

Turning a Liability into an Asset:

A Landfill Gas-to-Energy Project Development Handbook

Landfill Methane Outreach Program

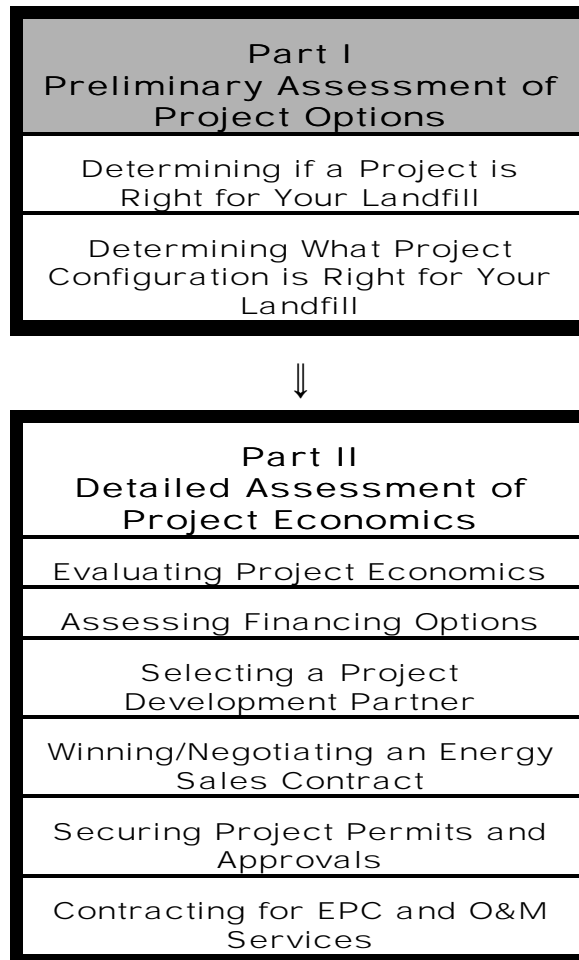
U.S. Environmental Protection Agency

September 1996

PART I

PRELIMINARY ASSESSMENT OF PROJECT OPTIONS

The Project Development Process



PART II

DETAILED ASSESSMENT OF PROJECT ECONOMICS

The Project Development Process

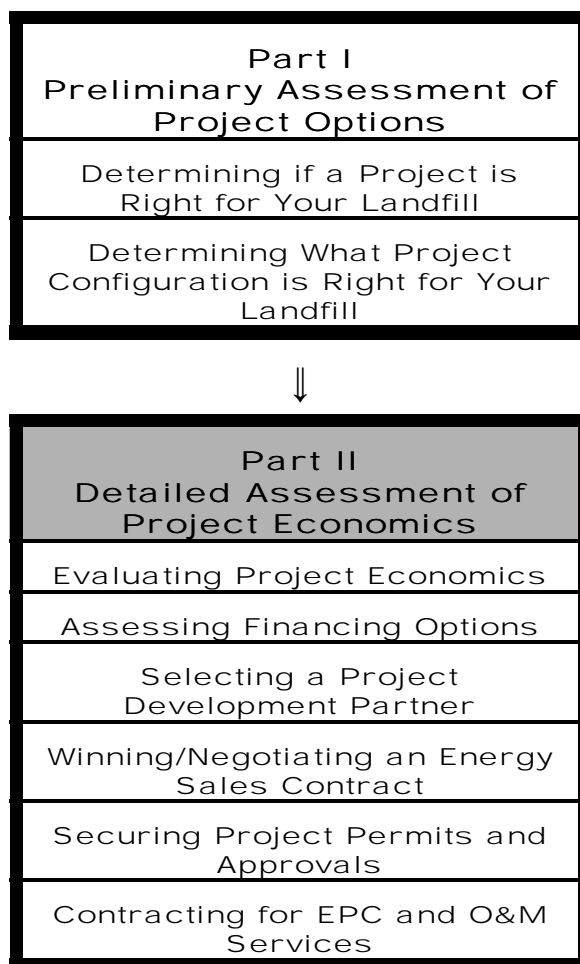


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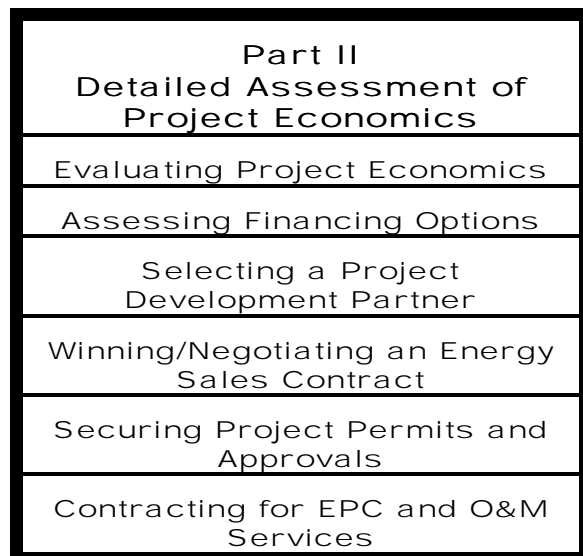
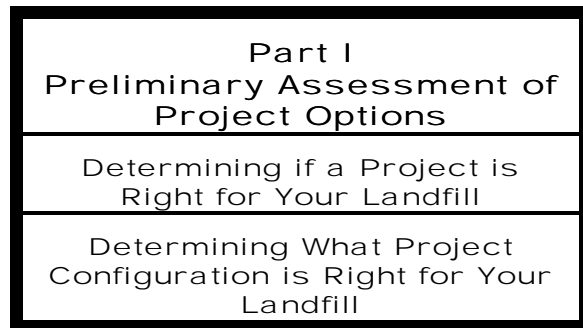
1. INTRODUCTION

Each person in the United States generates about 4.5 pounds of solid waste per day--almost one ton per year. Most of this waste is deposited in municipal solid waste landfills. As this landfilled waste decomposes (a process that may take 30 years or more), it produces landfill gas. Landfill gas contributes to the formation of smog and poses an explosion hazard if uncontrolled. Furthermore, because landfill gas is about 50 percent methane, it is both a potent greenhouse gas and a valuable source of energy.

Substantial opportunities exist across the country to harness this energy resource and turn what would otherwise be a liability into an asset. The purpose of this handbook is to help landfill owners, operators, and others considering landfill gas projects determine whether landfill gas energy recovery is likely to succeed at a particular landfill, and to clarify the steps involved in developing a successful project.

The handbook is organized according to the process of landfill gas project development, as the flowchart on this page illustrates. It contains two major sections: **Part I Preliminary Assessment of Project Options** provides the landfill owner/operator with basic screening criteria to assess the viability of a landfill energy recovery project and make a preliminary economic comparison of the primary energy recovery options; and **Part II Detailed Assessment of Project Options** outlines and discusses the major steps involved in development of a landfill gas energy recovery project, from estimating expenses and revenues to

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constructing and operating the project. The flowchart on this page can be found at the front of each chapter, with the current section and chapter highlighted. Additional information is contained in Appendices A through J of the handbook.

1.1 THE BENEFITS OF LANDFILL GAS ENERGY RECOVERY

Landfill gas energy recovery offers significant environmental, economic, and energy benefits. These benefits are enjoyed by many, including the landfill owner/operator, the project developer, the energy product purchaser and consumer, and the community living near the landfill.

1.1.1 Environmental Benefits

Landfill gas contains volatile organic compounds, which are major contributors to ground-level ozone and which include air toxics. When little is done to control them, these pollutants are continuously released to the atmosphere as waste decomposes. When landfill gas is collected and burned in an energy recovery system, these harmful pollutants are destroyed.

Regulations already require many landfills to collect their landfill gas emissions, and new federal air regulations will soon require additional control. Once the gas is collected, landfill owner/operators have two choices: (1) flare the gas; or (2) produce energy for sale or on-site use. Both options address local air quality and safety concerns, but only energy recovery capitalizes on the energy value of landfill gas, while displacing the use of fossil fuels. Offsetting coal and oil use further reduces emissions of a number of pollutants, including sulfur dioxide, a major contributor to acid rain, as well as the production of ash and scrubber sludge from utilities. Furthermore, landfill gas collection systems operated for energy recovery are often more carefully managed than those designed to flare the gas. This means that more of the gas generated in the landfill may be collected and combusted, with fewer emissions to the atmosphere.

Landfill gas energy recovery also has the potential to significantly reduce the risk of global climate change. Landfill gas is the single largest source of anthropogenic methane emissions in the United States, contributing almost 40 percent of these emissions each year. Reducing methane emissions is critical in the fight against global climate change because each ton of methane emitted into

the atmosphere has as much global warming impact as 21 tons of carbon dioxide over a 100 year time period. In addition, methane cycles through the atmosphere about 20 times more quickly than carbon dioxide, which means that stopping methane emissions today can make quick progress toward slowing global climate change.

1.1.2 Economic Benefits

New federal regulations, promulgated in March 1996, require several hundred landfills across the country to collect and combust their landfill gas emissions. Once installation and operation of a collection system is a required cost of doing business, incurring the extra cost of installing an energy recovery system becomes a more attractive investment. Sale or use of landfill gas will often lower the overall cost of compliance and, when site-specific conditions are favorable, the landfill may realize a profit.

More widespread use of landfill gas as an energy resource will also create jobs related to the design, operation, and manufacture of energy recovery systems and lead to advancements in U.S. environmental technology. Local communities will also benefit, in terms of both jobs and revenues, through the development of local energy resources at area landfills.

1.1.3 Energy Benefits

Landfill gas is a local, renewable energy resource. Because landfill gas is generated continuously, it provides a reliable fuel for a range of energy applications, including power generation and direct use. Electric utilities that participate in landfill gas-to-energy projects can benefit by enhancing customer relations, broadening their resource base, and gaining valuable experience in renewable energy development. Landfill gas power projects provide important demand side management benefits, as transmission losses from the point of generation to the point of consumption are negligible. The National Association of Regulatory Utility Commissioners recognized the value of landfill gas as an energy resource when it adopted a resolution in March 1994 "urging regulators to focus their regulatory attention on the landfill gas resources in their States to determine the role that energy from landfill gas can play as an energy resource for utilities and their customers." Industrial facilities, universities, hospitals, and other energy users can benefit by tapping into landfill gas, a low-cost, local fuel source.

1.2 THE EPA LANDFILL METHANE OUTREACH PROGRAM

The EPA Landfill Methane Outreach Program encourages landfill owner/operators to develop landfill gas energy recovery projects wherever it makes economic sense to do so. EPA estimates that over 700 landfills across the United States could install economically viable landfill gas energy recovery systems, yet only about 140 energy recovery facilities are in place. Through the Outreach Program, EPA is working with municipal solid waste landfill owners and operators, states, utilities, industry and other federal agencies to lower the barriers to economic landfill gas energy recovery.

This handbook is one component of the Landfill Methane Outreach strategy for overcoming information barriers to development of energy recovery projects. By providing information that can be used to assess project feasibility and outlining the project development process to landfill owner/operators and others considering energy recovery projects, this handbook can help spur development of successful projects. For more information on the Outreach Program, contact EPA's Hotline at 1-888-STAR-YES.

1.3 HOW TO USE THIS HANDBOOK

If you are a landfill owner/operator or anyone considering a landfill gas-to-energy project you can use this handbook to conduct a preliminary assessment of the potential for your landfill to support an energy recovery project. First, review Section 2.1 with the parameters of your landfill in mind. If your landfill meets the basic screening criteria (or has site-specific factors that make it a good candidate for energy recovery), use the information provided in Section 2.2 to develop a rough estimate of available landfill gas. Next, examine the economic comparison in Chapter 3, referring to the landfill gas estimate closest to that for your landfill, and determine which energy recovery option may be most cost-effective. Finally, carefully review Part II of the handbook (Chapters 4 to 10) to gain an understanding of the steps involved in developing an energy recovery project at your landfill. You may want to consult some of the references listed in Appendix H for more detailed information on the gas being generated at your landfill and the collection and energy recovery system you are considering.

This handbook is not meant to be an exhaustive guide to the landfill gas development process, nor is it a technical guide to project design. Once you have decided to pursue a

gas-to-energy project, you may want to consult experts with experience in project development as well as technical resources regarding construction, equipment, operation, and other aspects of project design. The Landfill Methane Outreach Program can provide you with a list of landfill gas-to-energy project developers, engineers, equipment manufacturers, financiers, and end-users, and Appendix G contains a listing of organizations that can refer you to additional experts in project design, development, and operation.

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2. DETERMINING IF A PROJECT IS RIGHT FOR YOUR LANDFILL

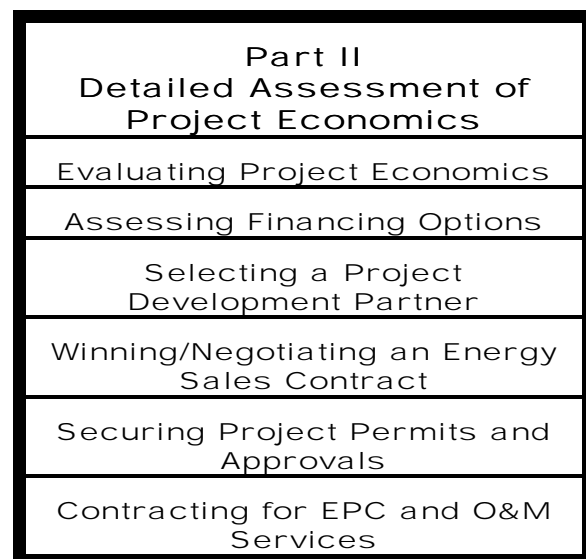
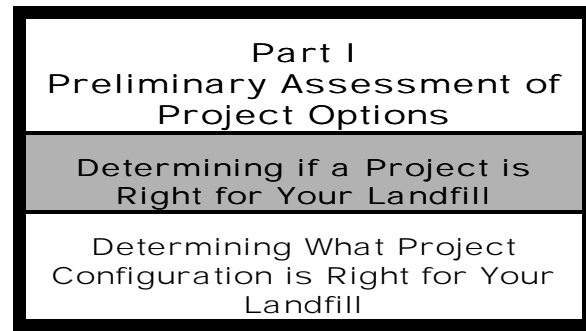
The preliminary assessment of project options includes two major phases. First, the landfill owner/operator must determine whether a project is likely to succeed at his or her landfill. If the landfill meets the criteria for a conventional energy recovery project--or has other characteristics that make it a good energy recovery candidate--the owner/operator next determines what project configuration would be most cost-effective. This chapter describes the steps involved in the first of these phases.

Determining if an energy recovery project may be right for a particular landfill is the first phase involved in assessing project options, as shown in the flowchart on this page. This phase involves two steps:

- (1) application of basic screening criteria to determine if the landfill has the characteristics that apply generally to successful landfill gas energy recovery projects; and
- (2) estimation of the quantity of landfill gas that can be collected, as gas quantity is a critical factor in determining whether landfill gas energy recovery is a viable option.

The approximately 140 landfill gas energy recovery projects operating in the United States exhibit a wide range of landfill characteristics and gas flows, illustrating that

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many different types of landfills can support successful projects. Nevertheless, there are a few basic criteria that can be used for site screening to determine whether a project is *likely* to succeed at a particular landfill. For example, a large landfill that is still receiving waste will, in general, be an attractive candidate for landfill energy recovery. These and other criteria, and how to apply them, are discussed in Section 2.1.

For landfills that appear to be candidates for energy recovery, estimating landfill gas flows is essential. The amount of gas that can be collected is dependent upon a number of factors, including, among others, the amount of waste in place, the depth of the landfill, the age and status of the landfill, and the amount of rainfall the landfill receives. There are several ways to estimate landfill gas quantity, ranging from "back of the envelope" calculations to sophisticated computer modeling. Not surprisingly, both the degree of certainty that collected gas quantity will match the estimate and the cost of developing the estimate increase along this spectrum. Section 2.2 describes some of the various methods available to estimate the gas generation and collection rate.

If the landfill under consideration for energy recovery already has a gas collection system that is likely to be representative of the area from which gas will be drawn (i.e., not just perimeter wells), the task of estimating gas quantity is essentially complete. The quantity of gas collected with the current system can be used to estimate the amount of gas available for energy recovery.

2.1 STEP 1: BASIC SCREENING FOR PROJECT POTENTIAL

The purpose of basic screening is to quickly identify landfills that are good candidates for energy recovery. The questions in Box 2.1 can help guide a landfill owner/operator through the process of evaluating screening criteria, which are identified below. It is likely that the best candidates for energy recovery will have the following characteristics:

Box 2-1 Is a Project Right for Your Landfill?

A. Is your landfill a municipal solid waste landfill?

If not, you may encounter some additional issues in project development due to the presence of hazardous or non-organic waste in the landfill. Stop and consult an energy recovery expert.

B. Add your score for the next 3 questions:

1. How much waste is in your landfill? Score

<u>Tons</u>	<u>Score</u>	
≥ 3 million	40	
1-3 million	30	
0.75-1 million	20	
< 0.75 million	10	_____

2. Is your fill area at least 40 feet deep?

Yes = 5

No = 0

+ _____

3(b). 3. Is your landfill currently open? If yes, answer 3(a). If no, answer

(a) How much waste will be received in the next 10 years?

For each 500,000 ton, score 5 points. + _____

(b) If closed < 1 year, enter 0.

If closed ≥ 1 year, multiply each year since closure by 5,

and

subtract that amount from the total. - _____

Total your answers to questions 1-3: = _____

C. If your score is:

≥ 30: Your landfill is a good candidate for energy recovery (go to section D).

20-30: Your landfill may be a good candidate for energy recovery, particularly if a factory or other energy user with constant fuel demand is located within a few miles of the landfill (go to Section D).

< 20: Your landfill may not be a good candidate for conventional energy recovery options. However, you may want to consider on-site or alternative uses for the landfill gas.

D. If your landfill is a good candidate, answer the following questions:

1. Are you now collecting gas at your landfill (other than from perimeter wells), or do you plan to do so soon for regulatory or other reasons? If yes, your landfill may be an excellent candidate for energy recovery.

2. (a) Is annual rainfall less than or equal to 25 inches per year?
(b) Is construction and demolition waste mixed into the municipal waste or is it a large portion of total waste?

If yes to questions D.2(a) or D.2(b), your annual landfill gas production may be lower than otherwise expected. Your landfill may still be a strong candidate, but you may want to lower your

- At least one million tons of waste in place;
- Still receiving waste, or closed for not more than a few years; and
- Landfill depth of 40 feet or more.

Landfills that meet these criteria are likely to generate enough landfill gas to support a gas-to-energy project. An industry rule of thumb places the "economically viable" gas generation rate at one million cubic feet per day (1 mmcf/day). However, this figure, like the screening criteria, should be considered only as a guideline - in fact, many landfills that do not meet all of the criteria could support successful energy recovery projects because of important site-specific characteristics. For example, energy recovery projects are currently underway at landfills with as little as 50,000 tons of waste in place, gas flows of 20,000 cf/day and depths of just 10 feet. In addition, about forty percent of existing and planned projects are sited at closed landfills, with about half of these closed during the 1980s [Berenyi and Gould, 1994].

Landfills that already collect their landfill gas, or that will be required to collect the gas, may be attractive candidates for energy recovery, especially if they meet most or all of the other criteria. Once installation and operation of a collection system is a required cost of doing business, the extra cost of energy recovery becomes a more attractive investment. In this situation, energy recovery may be the most cost-effective compliance strategy, even if it does not provide a net profit.

Some additional characteristics may also be indicative of energy recovery potential. These include:

- Climate: Moisture is an important medium for the bacteria that break down the waste. In areas with very low rainfall (i.e., less than 25 inches per year), yearly generation of landfill gas is likely to be relatively low. Therefore, less gas may be available for energy recovery each year at arid landfills (although gas production may continue for a longer period of time than in a wetter environment).
- Waste Type: Methane is generated when organic waste, such as paper and food scraps, decomposes. Therefore, landfills (or cells within landfills) that

contain large proportions of synthetic or slowly-decomposing organic waste, such as plastic and construction/demolition waste, may be less attractive candidates for energy recovery.

- Nearby Energy Use: A smaller landfill may still be a good candidate for energy recovery if there is a use for the gas at or near the landfill. Such landfills should not be discounted without exploration of direct gas use options.

2.2 STEP 2: ESTIMATING GAS QUANTITY

Once the landfill owner/operator has determined that energy recovery may be attractive, the next step is to estimate landfill gas flow. Information from this step is of critical importance in determining the technical specifications of the project and in assessing its economic feasibility. There are a variety of methods, ranging from very basic desktop estimates to actual field tests, as described below. Because both the cost and the reliability of the estimates increases for more detailed methods, it is recommended that the basic estimation approaches be used first, and more detailed methods be used (if warranted) as project assessment progresses.

2.2.1 Methods for Estimating Gas Flow

Three gas flow estimation methods are presented below. The first two are relatively simple approaches that require limited site-specific information. Because landfill characteristics, and therefore gas generation rates, can vary substantially among landfills (even those with the same amount of waste in place), Methods A and B will provide only rough gas flow estimates. When using these methods, the landfill owner/operator should assume that actual gas flows may be 50 percent higher or lower. For example, lower gas flows may occur at landfills located in arid areas (i.e., receiving less than 25 inches of rainfall per year) or at landfills containing large amounts of construction/demolition debris. Method C, in contrast, relies on data from the landfill itself, and should provide more accurate estimates.

Method A: Simple Approximation

A *rough approximation* of landfill gas production can be estimated easily using the amount of waste in place as the only variable. The procedure described below for approximating gas production is derived from the ratio of waste quantity to gas flow observed in the many, often very

different, projects in operation. It reflects the **average** landfill that has an energy recovery project, and may not accurately reflect the waste, climate, and other characteristics present at a specific landfill. Therefore, it should be used primarily as a screening tool to determine if a more detailed assessment is warranted (such as can be developed using Method C).

The simple approximation method only requires knowledge of how much waste is in place at the target landfill. Based on their extensive experience at many landfills, industry experts have developed a rule of thumb that landfill gas generation rates range from 0.05 to over 0.20 cubic feet (cf) of gas per pound (lb) of refuse per year, with the average landfill generating 0.10 cf of landfill gas per lb per year [WMNA, 1992; Walsh, 1994].

Using this rule of thumb results in the following equation:

$$\text{Annual Landfill Gas Generation (cf)} = 0.10 \text{ cf/lb} \times 2000 \text{ lb/ton} \times \text{Waste-In-Place (tons)}$$

A sample calculation using this method is shown in Box 2.2. Because the amount of gas generated declines as waste ages in the landfill, the above gas generation estimate is only appropriate for the first year or two of project operation if no new waste is added. As a result, gas generation rates may be on the low end of the range for landfills that have been closed for several years. In addition, the landfill owner/operator should adjust downward his or her rough estimate of gas flows over the life of the project by 2 to 3 percent per year [Wolfe and Maxwell].

Box 2-1 Example Using Simple Approximation Method

For a landfill with one million tons of waste in place, this method yields a rough estimate of 200 million cubic feet of landfill gas per year, or about 550,000 cubic feet per day (cfd). The uncertainty associated with this estimate should be accounted for by adding and subtracting 50 percent, yielding a range for the landfill's gas flow of 275,000 to 825,000 cfd.

Method B: First Order Decay Model

The second approach -- a "First Order Decay Model" -- can be used to account for changing gas generation rates over the life of the landfill or a proposed project.

Understanding the rate of gas flow over time is critical to evaluating project economics (see Chapter 5). The first order decay model is more complicated than the rough approximation described above, and requires that the landfill owner/operator know or estimate five variables:

- the average annual waste acceptance rate;
- the number of years the landfill has been open;
- the number of years the landfill has been closed, if applicable;
- the potential of the waste to generate methane; and
- the rate of methane generation from the waste.

The basic first order decay model is as follows:

$$\text{LFG} = 2 L_o R (e^{-kc} - e^{-kt})$$

Where:

LFG = Total amount of landfill gas generated in current year (cf)
L_o = Total methane generation potential of the waste (cf/lb)
R = Average annual waste acceptance rate during active life (lb)
k = Rate of methane generation (1/year)
t = Time since landfill opened (years)
c = Time since landfill closure (years)

The methane generation potential, L_o, represents the total amount of methane that one pound of waste is expected to generate over its lifetime. Thus, it is much higher than the landfill gas generation constant used in Method A to represent landfill gas generation per year. The decay constant, k, represents the rate at which the methane will be released from each pound of waste. If these terms were known with certainty, the first order decay model would predict methane generation relatively accurately; however, the values for L_o and k are thought to vary widely, and are difficult to estimate accurately for a particular landfill.

The values for L_o and k are dependent in part on local climatic conditions and waste composition; therefore, a landfill owner/operator may want to consult others in the local area, with similar landfills who have installed gas collection systems to narrow the range of potential values. On March 12, 1996, EPA issued final regulations for the control of landfill gas at new and existing municipal solid waste landfills with design capacities of 2.5 million metric

tons or more¹. Affected landfills model their gas emissions using the first order decay model. The regulations include the following default values (as well as a non-methane organic compound default value of 4000 ppm, which a landfill can replace with site-specific data):

- $L_o = 2.72 \text{ cf/lb}$
- $k = 0.05/\text{year}$

Ranges for L_o and k values developed by an industry expert are presented in Table 2-1. Note that for different climatic conditions, the L_o (total amount of landfill gas generated) remains the same, but the k value (rate of landfill gas generation) changes, with dry climates generating gas more slowly.

Table 2-1 Suggested Values for First Order Decay Model Variables

Variable	Range	Suggested Values		
		Wet Climate	Medium Moisture Climate	Dry Climate
L_o (cf/lb)	0-5	2.25-2.88	2.25-2.88	2.25-2.88
k (1/yr)	0.00 3-0.4	0.1-0.35	0.05-0.15	0.02-0.10
Source: Landfill Control Technologies, "Landfill Gas System Engineering Design Seminar," 1994.				

Because of the uncertainty in estimating L_o and k , gas flow estimates derived from the first order decay model should also be bracketed by a range of plus or minus 50 percent. Box 2.3 shows a sample calculation using the first order decay model.

¹ 61 FR 9905, Tuesday March 12, 1996.

Box 2-1 Example Using First Order Decay Model

For a landfill with the following characteristics:

- open for 25 years;
- still accepting waste; and
- average annual waste acceptance rate of 40,000 tons

The first order decay model would yield a rough estimate of 310 million cubic feet of landfill gas per year, or about 850,000 cfd (using the NSPS k and L_0 values). The uncertainty associated with this estimate should be accounted for by adding and subtracting 50 percent, yielding a range for the landfill's gas flow of 425,000 to 1.3 million cfd.

Note that a landfill with the same amount of waste in place (i.e., one million tons) but a lower waste acceptance rate would have a lower gas flow rate, while a younger landfill that was taking in waste more quickly would have a higher gas flow rate. The choice of different values for k and L_0 in the first order decay model would also yield different gas flow estimates.

Method C: Pump Test

The most accurate method for estimating gas quantity, short of installing a full collection system, is to conduct a pump test. A pump test involves sinking test wells and installing pressure monitoring probes, then measuring the gas collected from the wells under a variety of controlled extraction rates. When conducting a pump test, it is important that the test wells are placed to be representative of the waste from which the gas will be eventually drawn, since gas generation rates may vary across the landfill.

A benefit of this method is that the collected gas can be tested for quality, as well as quantity. It should be analyzed for Btu content in addition to hydrocarbon, sulfur, particulate, and nitrogen content. Information obtained from a pump test is important since it is used in the design of the processing and energy recovery system, as well as in obtaining project financing.

The cost to drill test wells can range from \$5,000 to \$10,000 per well [Smithberger, 1994; Merry, 1994].

However, for budgetary purposes, the total cost of installing a well and extracting gas can be estimated to be approximately \$60 per linear foot, with a typical test well being 100 feet deep [Bilgri, 1995]. This estimate includes costs for the well pipe, pipe casing, backfill, and labor. The total number of wells required to accurately predict landfill gas quantity will depend on factors such as landfill size and waste homogeneity.

Other Estimation Methods

Landfill gas energy recovery experts, if consulted by the landfill owner/operator, will almost certainly want to review and verify estimates developed using the above methods, particularly estimates developed with Methods A or B. Each energy recovery expert has his or her own preferred method for estimating landfill gas quantity, and will likely want to use this method to verify estimates prepared using any of the above methods.

2.2.2 Correcting for Collection Efficiency

Before gas generation estimates developed from Methods A or B are used to size a collection/energy recovery system, it is necessary to correct for landfill gas collection efficiency. There are several factors which affect the overall collection efficiency of a landfill gas extraction system, which can vary from about 50 to over 90 percent. The permeability of the landfill's cover layer will determine how much of the landfill gas generated will escape to the atmosphere; however, a portion of the landfill gas will escape through the cover of even the most tightly constructed and controlled collection system. Well spacing and depth, which are determined by economic and other site specific factors, also affect collection efficiency, as can bottom and side liners, leachate and water level, and meteorological conditions.

Collection systems operated for energy recovery may be more efficient than those where the collected gas is not put to productive use because each cubic foot of gas will have a monetary value to the owner/operator. In addition, newer systems may be more efficient than the average system in operation today. Nevertheless, there continues to be economic limits on the tightness of well spacing and other factors that are difficult or impossible to control. Therefore, a reasonable assumption for a newer collection system operated for energy recovery is 75 to 85 percent collection efficiency.

Multiplying the total landfill gas generation estimated by Methods A or B by 75 to 85 percent should yield a reasonable estimate of the landfill gas available for energy recovery. Even the results of Method C may have to be corrected for collection efficiency, since the results of the pump test may not provide an indication of gas flows across the landfill [Kraemer, 1995].

2.2.3 Comparing Your Gas Flow Rate to Existing Projects

For gas flow estimates to be meaningful, the landfill owner/operator must assess whether the available gas flow is sufficient to support an energy recovery project. The average energy recovery facility collects just over 2.5 million cubic feet per day (mmcf/d) of landfill gas. However, the ability of a particular gas flow to support an energy recovery project is largely a function of the energy purchaser's or user's needs. Existing project sizes range from 20,000 cfd to over 30 mmcf/d, and about one-third of the projects (existing and planned) use less than 1 mmcf/d [Berenyi and Gould, 1994]. Two projects spanning much of this range are described in Box 2.4. Information on which project configurations are most cost-effective for a particular gas flow rate is provided in the next section and in Part II of this handbook.

Box 2-1 Energy Recovery at Two Very Different Landfills

Puente Hills Landfill

The Puente Hills Landfill in Whittier, CA, receives 12,500 tons of waste per day, and collects over 30 mmcf/d from 400 vertical wells and 50 miles of horizontal collection piping. The Los Angeles County Sanitation Districts, which operates the landfills, uses the landfill gas in three ways:

- in a boiler/steam turbine configuration, located at the landfill, to generate almost 50 MW of power;
- as vehicle fuel, in the form of compressed natural gas;
- as fuel for a boiler at Rio Hondo college, located one mile away

Puente Hills is the largest landfill energy recovery power project in the United States. It has been operational since the early 1980s.

City of Keene, New Hampshire Landfill

The City of Keene is using landfill gas from a 15 acre landfill to power its new recycling/transfer station. The station, located at the City landfill, requires three-phase electricity for its process machinery but the local electric utility's nearest three-phase power line stops several miles away from the site. By instead using gas from the landfill, the City will save more than \$200,000 over the expected life of the landfill gas project.

A blower pulls the gas from 10 vertical wells, through simple particle and moisture filters to the (internal combustion) engine-generator set. The recycling/transfer station equipment runs 24 hours per day but is only heavily used during facility working hours. The landfill gas-to-energy system provides peak operating loads at about 180 kW, with the average over a full day at 50 kW. The project was built for a total of \$280,000, including the gas collection system, and is expected to cost approximately \$25,000 per year in operating costs. [Allan McLane, Vermont Energy Recovery]

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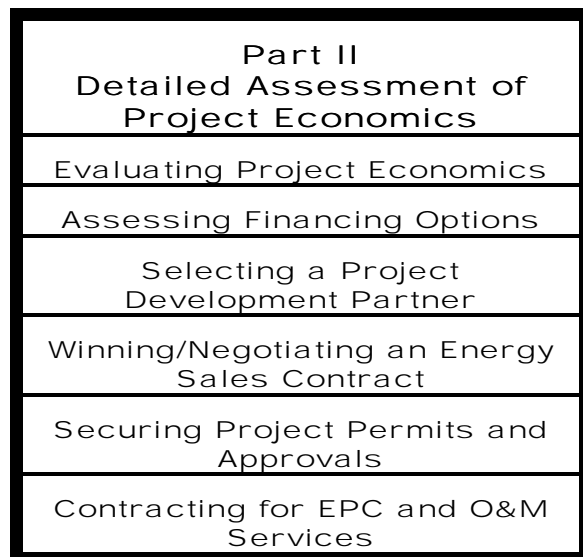
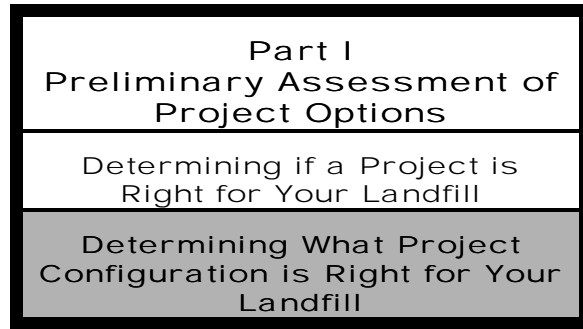
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3. DETERMINING WHAT PROJECT CONFIGURATION IS RIGHT FOR YOUR LANDFILL

After estimating the quantity of gas available for energy conversion, the landfill owner/operator must decide which conversion option or options make the most sense for the landfill (see Flowchart). Several options may be appropriate. The best choice will depend upon site-specific factors, including the characteristics of the landfill as well as local energy markets. Section 3.1 describes the basic energy conversion options and how a landfill owner/operator can assess which one(s) will be most cost-effective at his or her landfill. Section 3.2 compares the major energy recovery options on a cost basis for three landfill sizes.

An important consideration in the evaluation of energy conversion options is the availability of federal, state, or local incentives. For example, Section 29 of the Internal Revenue Service Code provides a tax credit for sale of landfill gas to an unrelated party, and the Department of Energy provides an incentive for publicly owned landfill gas facilities that generate electricity. Several states and some localities also provide incentives to landfill projects, such as low cost loan programs or other subsidies. Landfill owner/operators should determine if incentives are available and, if so, how a project must be structured to take advantage of them. (See Chapter 5 for more information on incentives).

The Project Development Process

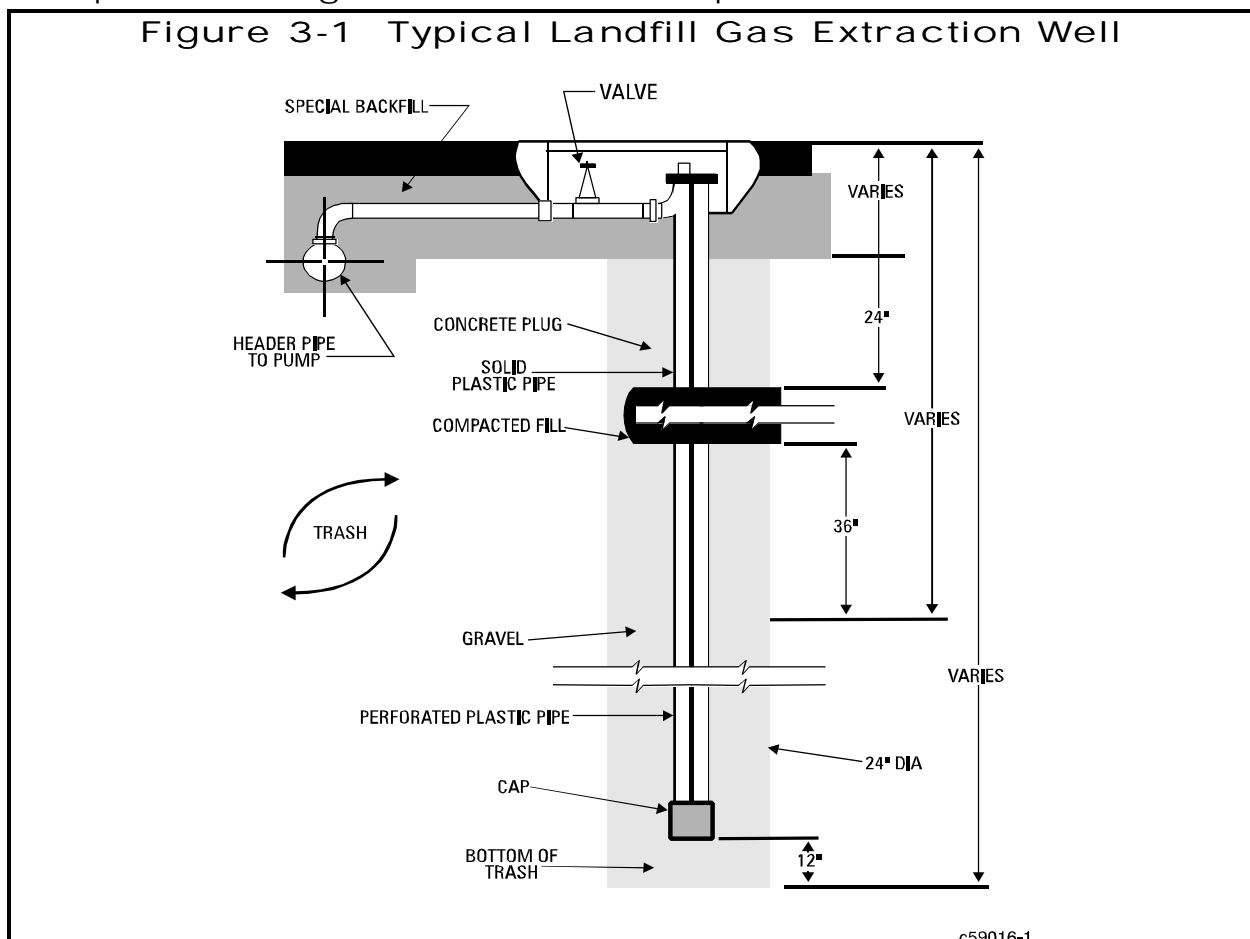


3.1 OPTIONS FOR USING LANDFILL GAS

Landfill gas can be converted into useable energy in a number of ways, including use as a fuel for internal combustion engines or turbines to produce electricity, direct use of the gas as a boiler fuel, and upgrade to pipeline quality gas, among others. Each of these options entails three basic components: (1) a gas collection system and backup flare; (2) a gas treatment system; and, (3) an energy recovery system. This section provides a brief overview of each component, and outlines the major characteristics of energy recovery systems that determine their applicability at a given site.

3.1.1 Collection System and Flare

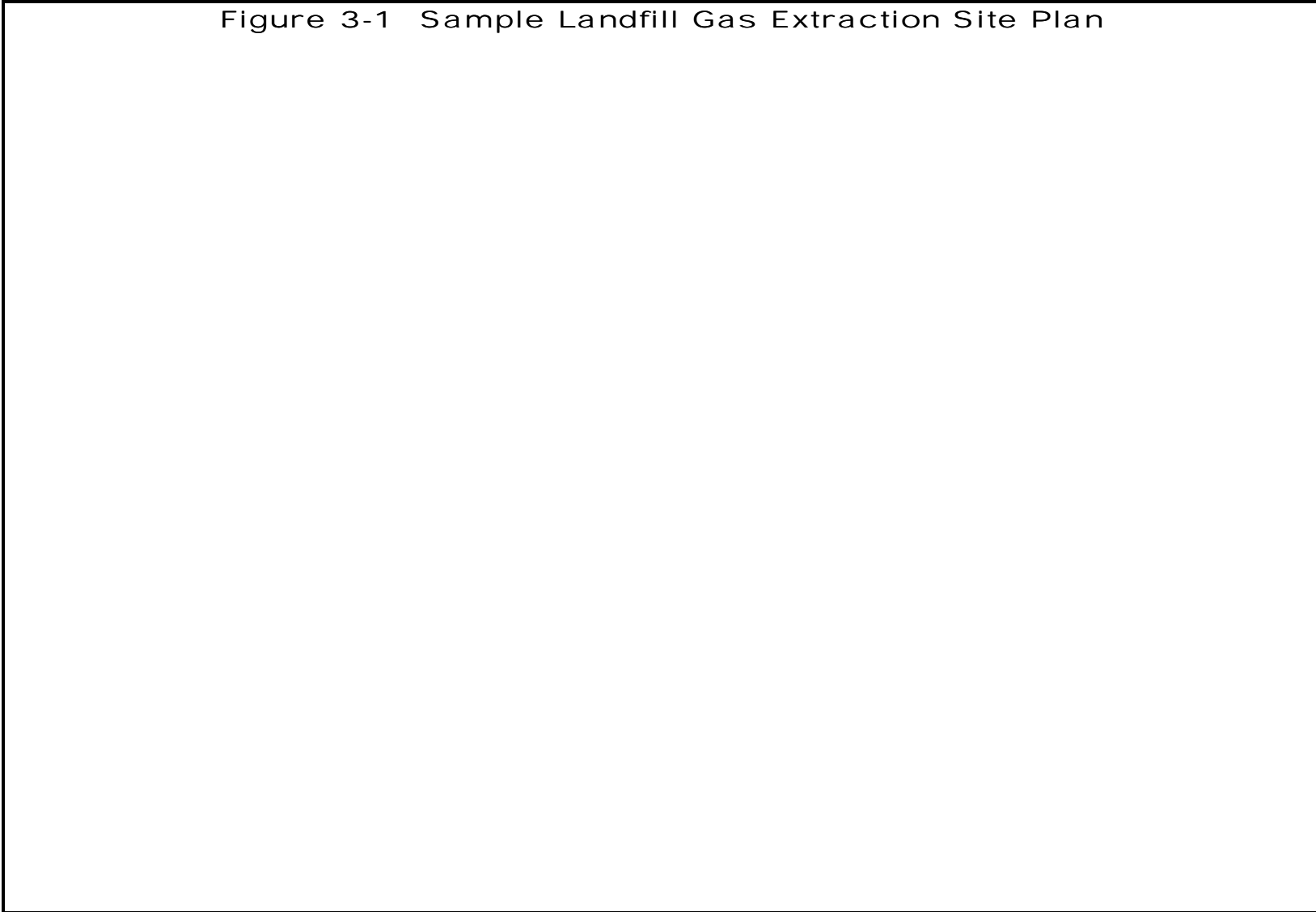
Typical landfill gas collection systems have three central components: collection wells; a condensate collection and treatment system; and a compressor. In addition, most landfills with energy recovery systems will have a flare for the combustion of excess gas and for use during equipment down times. Each of these components is described below, followed by a brief discussion of collection system and flare costs. Figure 3.1 illustrates the design of a typical landfill gas extraction well, and Figure 3.2 shows a sample landfill gas extraction site plan.



Gas Collection Wells

Gas collection typically begins after a portion of a landfill (called a cell) is closed. There are two collection system configurations: vertical wells and horizontal trenches. Vertical wells are by far the most common type of well used for gas collection. Trenches may be appropriate for deeper landfills, and may be used in areas of active filling. Regardless of whether wells or trenches are used, each wellhead is connected to lateral piping, which transports the gas to a main collection header. Ideally, the collection system should be designed so that the operator can monitor and adjust the gas flow if necessary.

Figure 3-1 Sample Landfill Gas Extraction Site Plan



Condensate Collection and Treatment

An important part of any gas collection system is the condensate collection and treatment system. Condensate forms when warm gas from the landfill cools as it travels through the collection system. If condensate is not removed, it can block the collection system and disrupt the energy recovery process. Condensate control typically begins in the field collection system, where sloping pipes and headers are used to allow drainage into collecting ("knockout") tanks or traps. These systems are typically augmented by post-collection condensate removal as well. Some of the methods for disposal of condensate are discharge to the public sewer system, on-site treatment, and recirculation to the landfill. The best method for a particular landfill will depend upon the characteristics of the condensate (which may vary depending on site-specific waste constituents), regulatory considerations, and the cost of treatment and disposal.

Blower/Compressor

A blower is necessary to pull the gas from the collection wells into the collection header, and a compressor may be required to compress the gas before it can enter the energy recovery system. The size, type, and number of blowers and compressors needed depends on the gas flow rate and the desired level of compression, which is typically determined by the energy conversion equipment.

Flare

A flare is simply a device for igniting and burning the landfill gas. Flares are considered a component of each energy recovery option because they may be needed during energy recovery system startup and downtime. In addition, it may be most cost-effective to gradually increase the size of the energy recovery system and to flare excess gas between system upgrades (e.g., before addition of another engine). Flare designs include open (or candle) flares and enclosed flares. Enclosed flares are more expensive but may be preferable (or required) because they allow for stack testing and can achieve slightly higher combustion efficiencies. In addition, enclosed flares may reduce noise and light nuisances.

Collection System Costs

Total collection system costs will vary widely, based on a number of site specific factors. If the landfill is deep,

collection costs will tend to be higher due to the fact that well depths will need to be increased. Collection costs also increase with the number of wells installed. Table 3-1 presents estimated capital and operating and maintenance costs for collection systems (including flares) at typical landfills with 1, 5, and 10 million metric tons of waste in place. For a landfill with 1 million metric tons of waste, collection system and flare capital costs will likely be approximately \$628,000, increasing to about \$2.1 million for a 5 million metric ton landfill and \$3.6 million for a 10 million metric ton landfill. Annual operation and maintenance costs for the landfill gas collection system may range from \$89,000 for the typical 1 million metric ton landfill, increasing to \$152,000 for the 5 million metric ton landfill and \$218,000 for the 10 million metric ton landfill. [All cost data are in 1994 dollars.]

Flaring costs have been incorporated into the estimated costs of landfill gas collection systems (which are presented in Table 3.1 and in more detail in Chapter 5), since excess gas may need to be flared at any time, even if an energy recovery system is installed. Flare systems typically account for 5 to 15 percent of the capital cost of the entire collection system (i.e., including flares). For a typical landfill with 1 million metric tons of waste in place, flare system capital costs will be approximately \$88,000, increasing to about \$146,000 for a 5 million metric ton landfill and \$205,000 for a 10 million metric ton landfill.¹ Note, however, that flare costs will vary with local air pollution control monitoring requirements and the owner's own safety requirements. For example, if it is necessary to enclose the flare in a building for security or climatic reasons, the proceeding cost figures would increase by approximately \$100,000 [Nardelli, 1993].

Annual operation and maintenance costs for flare systems are less than 10 percent of the total collection system costs, and thus range from approximately \$8,000 for a 1 million metric ton landfill, increasing to \$15,000 for a 5 million metric ton landfill and \$21,000 for a 10 million metric ton landfill.

¹ The costs quoted here refer only to the flare system which includes the flare and monitoring equipment. Other items such as the blower and condensate handling system have been reflected in collection system costs.

Table 3-1 Summary of Representative Collection System Costs* (\$1994)

Landfill Size Waste in Place	Estimated Gas Flow (mcf/day)	Capital Costs (\$000)	Annual O&M Costs (\$000)
1 million metric tons	642	628	89
5 million metric tons	2,988	2,088	152
10 million metric tons	5,266	3,599	218

* Collection system costs include flaring costs.

3.1.2 Gas Treatment Systems

After the landfill gas has been collected, and before it can be used in a conversion process, it must be treated to remove any condensate that is not captured in the knockout tanks, as well as particulates and other impurities. Treatment requirements depend on the end use application. Minimal treatment is required for direct use of gas in boilers, while extensive treatment is necessary to remove CO₂ for injection into a natural gas pipeline. Power production applications typically include a series of filters to remove impurities that could damage engine components and reduce system efficiency.

The cost of gas treatment depends on the gas purity requirements of the end use application; the cost to filter the gas and remove condensate for power production is considerably less than the cost to remove carbon dioxide and other constituents for injection into a natural gas pipeline or for conversion to vehicle fuel. These costs are incorporated into the energy recovery system costs presented in Section 3.1.3 below.

3.1.3 Energy Recovery System

The goal of a landfill gas-to-energy project is to convert landfill gas into a useful energy form such as electricity, steam, boiler fuel, vehicle fuel, or pipeline quality gas. There are several technologies that can be used to maximize the value of landfill gas when producing these energy forms, the most prevalent of which are:

- (1) direct medium-Btu gas use
- (2) power production/cogeneration
- (3) sale of upgraded pipeline quality gas

The best configuration for a particular landfill will depend upon a number of factors including the existence of an available energy market, project costs, potential revenue sources, and many technical considerations. This section focuses on the technical issues that determine a project's feasibility, and, more specifically, on the technical issues related to direct use and power production, since these are the most common recovery options. Section 3.2 provides more information on choosing among the potential energy recovery technologies.

Option 1: Sale of Medium-Btu Gas

The simplest and often most cost-effective use of landfill gas is as a medium-Btu fuel for boiler or industrial process use (e.g., drying operations, kiln operations, and cement and asphalt production). In these projects, the gas is piped directly to a nearby customer where it is used in new or existing combustion equipment as a replacement or supplementary fuel. Only limited condensate removal and filtration treatment is required, but some modification of existing equipment may be necessary. There are currently about 30 direct use landfill gas projects in operation in the United States, and others are under development [Thorneloe, Pacey, 1994]. Box 3.1 provides specific examples of how landfill gas is being used as a medium-Btu fuel in some of these projects.

Before landfill gas can be used by a customer, a pipeline must first be constructed to access the supply. Pipeline construction costs can range from \$250,000 to \$500,000 per mile;² therefore, proximity to the gas customer is critical for this option. Often, a third party

Box 3.1 Examples of Direct Use Applications

- The City of Industry, CA has found several uses for landfill gas at its Recreation/Convention Center. Landfill gas is used in boilers to provide hot water for laundry and space heating for the Convention Center. The medium-Btu fuel is also used to heat the Center's swimming pool.
- The Kentucky-Tennessee Clay Company, located in Aiken County, SC, burns landfill gas in its rotary dryer to dry kaolin clay before shipment.
- Ogden Martin Systems, Inc. operates a waste-to-energy plant in Huntsville, AL to supply the steam needs of the U.S. Army's Redstone Arsenal. Landfill gas is used in a supplementary boiler at the waste-to-energy plant to meet the Arsenal's additional steam needs during peak demand periods [Mahin, 1991].
- In Langely, British Columbia, landfill gas is used in a greenhouse to provide heating and CO₂ for growth enhancement [Thorneloe, Pacey, 1994].
- Methane collected from the Acme Landfill in Martinez, CA is used at the Contra Costa Wastewater Treatment Facility.

developer is involved in the project who will assume the cost of installing the pipeline.

The customer's gas requirements are also an important consideration when evaluating a sale of medium-Btu gas. Because there is no economical way to store landfill gas, all gas that is recovered must be used as available, or it is

²Pipeline construction costs vary due to terrain differences, right-of-way costs, and other site-specific factors.

essentially lost, along with associated revenue opportunities. Therefore, the ideal gas customer will have a steady, annual gas demand compatible with the landfill's gas flow. In situations where a landfill's gas flow is not enough to support the entire needs of a facility, it may still be used to supply a portion of needs. For example, some facilities have only one piece of equipment (e.g., a main boiler) or set of burners dedicated to burn landfill gas. They also may have equipment that can use landfill gas along with other fuels.

Table 3-2 gives the expected annual gas flows on a MMBtu basis from different sized landfills. While actual gas flows will vary, these numbers may be used as a first step toward determining the compatibility of customer gas requirements and landfill gas output. A general rule of thumb to use when comparing boiler fuel requirements to landfill gas output is that approximately 8,000 to 10,000 pounds per hour of steam can be generated for every 1 million metric tons of waste in place at a landfill.³ Using this rule of thumb, it can be estimated that a 5 million metric ton landfill would support the needs of a large facility requiring about 50,000 pounds per hour of steam for process use.

Table 3-1 Landfill Gas Flows Based on Landfill Size

Landfill Size	1 MM Mg	5 MM Mg	10 MM Mg
LFG Output (MMBtu/year) ¹	100,000	490,000	850,000
Steam Flow Potential (lbs/hr)	10,000	45,000	85,000

¹ Assumes a 90% capacity (i.e., availability) factor
Output figures reflect rounding

If an ideal customer is not accessible, then it may be possible to create a steady gas demand by serving multiple customers whose gas requirements are complementary. For example, an asphalt producer's summer gas load could be combined with a municipal building's winter heating load to create a year-round demand for landfill gas.

Equipment modifications or adjustments may be necessary to accommodate the lower Btu value of landfill

³ This rule of thumb is based on steam delivery at 50 psig, saturated.

gas, and the costs of modifications will vary. Costs will be minimal if only boiler burner retuning is required. However, boiler burner retrofits are typically customized, and total installation costs can range from \$120,000 for a 10,000 lb/hr boiler to \$300,000 for an 80,000 lb/hr boiler [Brown, 1995]. As with pipeline construction costs, a third party project developer may assume the costs of equipment modifications or additions. This was the case when Natural Power, Inc. paid \$600,000 to install a new 26,000 lb/hr Cleaver-Brooks boiler to burn landfill gas to serve the steam needs of Ajinomoto USA, Inc., a pharmaceutical plant [Augenstein, Pacey, 1992].

Operation and maintenance (O&M) costs associated with using landfill gas in boilers, kilns, dryers, or other industrial equipment are typically equivalent to O&M costs when using conventional fuels. In general, O&M costs will depend on how well the equipment is maintained and how well the gas collection system is controlled. Some O&M considerations when using landfill gas as a medium-Btu fuel are listed in Box 3.2.

Box 3.1 Considerations When Using Landfill Gas as a Medium-Btu Fuel

It is important to consider the unique aspects of collecting and using landfill gas in equipment such as boilers, kilns, or dryers. Examples of considerations that can help to ensure optimal equipment performance include:

- Moisture content -- Landfill gas generally has three to seven percent moisture when it is collected. Sloped piping and condensate traps must be used to avoid water blockage in landfill gas piping or blowers which can be a cause of system interruptions (e.g., water can trip a gas blower or cause a loss of flame in a boiler).
- Lower flame temperature -- Landfill gas has a lower flame temperature than natural gas, and thus may result in lower superheater temperatures in boilers. Boilers may therefore require larger superheaters to accommodate the use of landfill gas.
- Lower Btu value -- The heating value of landfill gas can be reduced if collection wells draw in large amounts of air or if breaks in the collection piping occur. Good design and operating practices can prevent such problems [Eppich and Cosulich, 1993].

Option 2: Power Generation

The most prevalent use for landfill gas is as a fuel for power generation, with the electricity sold to a utility and/or a nearby power customer. Power generation is advantageous because it produces a valuable end product--electricity--from waste gas. Facilities that use landfill gas to generate electricity can qualify as a "small power producer" under the Public Utilities Regulatory Policy Act (PURPA), which requires electric utilities to purchase the output from such facilities at the utility's avoided cost. The electricity can in some cases be used on-site to displace purchased electricity or be sold to a nearby electricity user (e.g., municipality, industrial).

Cogeneration is an alternative to producing electricity only. Cogeneration systems produce electricity and thermal energy (i.e., steam, hot water) from one fuel source. Whereas the thermal efficiencies of electricity-only generation range from 20% to 50%, cogeneration systems can achieve substantially higher efficiencies by putting to use the "waste" heat that is a by-product of most power generation cycles. Thermal energy cogenerated by landfill gas projects can be used on-site for heating, cooling, and/or process needs, or piped to a nearby industrial or commercial user to provide a second revenue stream to the project.

Several good conversion technologies exist for generating power -- internal combustion engines, combustion turbines, and boiler/steam turbines -- each of which is described below. Box 3.3 highlights important aspects of each option. In the future, other technologies, such as fuel cells, may also become commercially available. Box 3.4 provides some discussion on the design considerations when sizing a landfill gas power project.

Box 3.1 Comparison of Electricity Generation Technologies

	<u>IC Engines</u>	<u>Combustion Turbines</u>	<u>Steam Turbine/Boiler</u>
Typical Project Size (MW)	≥ 1	> 3	> 8
Landfill Gas Requirements (mcf/day)	≥ 625	> 2,000	> 5,000
Typical Capital Costs (\$/kW)	1,100 - 1,300	1,200 - 1,700	2,000 - 2,500
Typical O&M Costs (¢/kWh)	1.8	1.3 - 1.6	1.0 - 2.0
Electric Efficiency (%)	25 - 35	20 - 28 (CT) 26 - 40 (CCCT)	20 - 31
Cogeneration Potential	Low	Medium	High
Compression Requirements (Input Gas Pressure (psig))	Low (2 - 35)	High (165+)	Low (2 - 5)
Advantages	<ul style="list-style-type: none"> • Low cost • High efficiency • Most common technology 	<ul style="list-style-type: none"> • Corrosion resistant • Low O&M costs • Small physical size • Low NO_x emissions 	<ul style="list-style-type: none"> • Corrosion resistant • Can handle gas composition and flow variations

Internal Combustion Engine

Box 3.1 Design Considerations When Sizing Power Projects

Determining the optimum size for a landfill gas power project requires a careful balance between maximizing electricity production and landfill gas use, and minimizing the risk of insufficient gas supplies in later years. The challenge arises because landfill gas production rates change over time. Gas generation may be increasing at an open landfill or decreasing at a closed landfill. System designers must also consider factors such as current and future electricity payments, equipment costs, and any penalties for shortfalls in electricity output.

The optimum design and operating scenario for a particular landfill gas project is likely to fall somewhere between two general scenarios: (1) minimum gas flow design; and (2) maximum gas flow design. However, a third design scenario--a modular approach--may be used at landfills where gas flow rates are expected to change substantially over time.

(1) Minimum Gas Flow Design. In this scenario, the electric generation equipment is sized based on the minimum expected gas flows over the life of the project. This ensures that the fuel supply (i.e., landfill gas) is seldom or never limited, and the electric generation system always runs at or near its maximum availability. This is a more conservative design, which puts a premium on constant and reliable electrical output over the project life. The disadvantage of this design is that some landfill gas will go unused in years when gas is plentiful; a lost opportunity to generate electricity and earn revenues. This may be a good design choice when project economics are robust and substantial contract penalties exist for shortfalls in electrical deliveries from the project. Capacity factors for this type of project are determined mainly by the generating equipment outage rates, which are approximately 6% to 10% for IC engine systems and 4% to 6% for combustion turbine-based systems.

(2) Maximum Gas Flow Design. In this scenario, the electric generating equipment is sized based on maximum gas flows over the life of the project. Landfill gas usage and electrical output are generally maximized, but there may be occasions when there is insufficient landfill gas supply to run the generating equipment at its rated capacity. This is a more aggressive design which puts a premium on full utilization of the landfill gas, and it has the advantage of higher electrical generating capacity, revenues, and landfill gas utilization than the first scenario. However, the disadvantages are that the project may suffer from periods when electrical output is below the rated capacity because of intermittent gas supply shortages or declining landfill production. This is an acceptable design if maximizing early-year revenues is critical, the power purchase contract is short-term, shortfall penalties are nonexistent, and/or alternate or augmented fuel supplies exist. Capacity factors for this type of project are determined by generating equipment outage rates and expected periods when fuel supply is limited. Part-load generating efficiency is a consideration in this type of project; IC engines and fuel cells generally exhibit better part-load performance (e.g., efficiency, wear) than CT-based systems.

(3) Changing Gas Flow Design. In this scenario, a series of smaller electric generating units is installed (or removed) over time as gas flow rate increases (or decreases). This modular approach helps ensure that landfill gas output is properly matched to equipment size, even when gas flow rates change. This approach has the dual benefit of maximizing gas use and electric output over time. However, a modular approach may also produce higher installation costs and lower efficiencies than other approaches. If gas flow is decreasing

The reciprocating internal combustion (IC) engine is the most commonly used conversion technology in landfill gas applications; almost 80 percent of all existing landfill gas projects use them [Thorneloe, 1992]. The reason for such widespread use is their relatively low cost, high efficiency, and good size match with the gas output of many landfills. In the past, the general rule of thumb has been that IC engines have generally been used at sites where gas quantity is capable of producing 1 to 3 MW [Thorneloe, 1992], or where landfill gas flows are approximately 625,000 to 2 million cubic feet per day at 450 Btu per cubic foot [Jansen, 1992].

IC engines are relatively efficient at converting landfill gas into electricity. IC engines running on landfill gas are capable of achieving efficiencies in the range of 25 to 35 percent. Historically, these engines have been about 5 to 15 percent less efficient when using landfill gas compared with natural gas operation, although the newest engine designs now sacrifice less than 5 percent efficiency when landfill gas is used [Augenstein, 1995]. Efficiencies increase further in cogeneration applications where waste heat is recovered from the engine cooling system to make hot water, or from the engine exhaust to make low pressure steam. IC engines adapted for landfill gas applications are available in a range of sizes, and can be added incrementally as landfill gas generation increases in a landfill.⁴

Environmental permitting may be an issue for some IC engine projects. IC engines typically have higher rates of nitrogen oxide (NO_x) emissions than other conversion technologies, so in some areas it may be difficult to obtain permits for a project using several IC engines. To address this problem, engine manufacturers are developing engines that produce less NO_x using improved combustion and other air emission control features. These advances should give plant designers more flexibility to use IC engines on large projects.

The installed capital costs for landfill gas energy recovery projects using IC engines are estimated to range from about \$1,100 per net kW output to \$1,300 per net kW output (1996 on-line date). These costs are indicative of power projects at landfills ranging in size from 1 million

⁴The most commonly used IC engines for landfill gas applications are rated at about 800 and 3,000 kW.

metric tons to 10 million metric tons of waste in place, and the costs include the engine, auxiliary equipment, interconnections, gas compressor, construction, engineering,

and soft costs. (Chapter 5 provides more detail on technology costs.) The costs associated with the landfill gas collection system are not included in these cost estimates.

Combustion Turbine

Combustion turbines (CTs) are typically used in medium to large landfill gas projects, where landfill gas volumes are sufficient to generate a minimum of 3 to 4 MW (i.e., where gas flows exceed approximately 2 million cfd). This technology is competitive in larger landfill gas electric generation projects because, unlike most IC engine systems, CT systems have significant economies of scale. The cost per kW of generating capacity drops as CT size increases, and the electric generation efficiency generally improves as well.

Simple-cycle CTs applicable to landfill gas projects typically achieve efficiencies of 20 to 28 percent at full load; however, these efficiencies drop substantially when the unit is running at partial load. Combined-cycle configurations, which recover the waste heat in the CT exhaust to make additional electricity, can boost the system efficiency up to approximately 40 percent, but this configuration is also less efficient at partial load [EPA, 1993]. One of the primary disadvantages of CTs is that they require high gas compression (165 pounds per square inch (psig) or greater), causing high parasitic load loss. This means that more of the plant's power is required to run the compression system, as compared to other generator options [WMNA, 1992]. An advantage is that turbines are much more resistant to corrosion damage than IC engines and have lower NO_x emission rates. In addition, combustion turbines are relatively compact and have low operations and maintenance costs in comparison to IC engines.

The installed capital costs for landfill gas energy recovery projects using simple cycle CTs are estimated to range from about \$1,200 per net kW output to \$1,700 per net kW output (1996 on-line date), for power projects at landfills ranging in size from 1 million metric tons to 10 million metric tons of waste in place, respectively. The costs include the CT, auxiliary equipment, interconnections, gas compressor, construction, engineering, and soft costs. (Chapter 5 provides more detail on technology costs.) The costs associated with the landfill gas collection system are not included in these cost estimates. For combined-cycle systems installed at landfills ranging in size from 5 million metric tons to 10 million metric tons of waste in place, the installed capital costs range from about \$1,400 per net kW

output to \$1,700 per net kW output (1996 on-line date). A combined-cycle system is not likely to be economically competitive at landfills with less than about 5 million metric tons of waste in place.

Boiler/Steam Turbine

The boiler/steam turbine configuration is the least used of the three landfill gas power conversion technologies. It is applicable mainly in very large landfill gas projects, where gas flows support systems of at least 8 to 9 MW (i.e., where gas flows are greater than 5 mmcf/d) [EPA, 1993]. The boiler/steam turbine consists of a conventional gas/liquid fuel boiler, usually a packaged unit, and a steam turbine generator that produces electricity. This technology usually requires a complete water treatment and cooling cycle, plus an ample source of process and cooling water. Boiler/steam turbine systems have a significantly higher cost per kW than either IC engines or CT systems, so only the largest landfill gas projects can afford to use this technology.

Fuel Cell

Fuel cells that run on landfill gas show great promise for power generation because of their modularity, small capacity, high efficiency, quiet operation, and low environmental impact. It is for these reasons that fuel cells may be an ideal technology for generating power from landfill gas, once they have been fully demonstrated. While a few fuel cells running on natural gas are in commercial operation, fuel cells capable of using landfill gas are still in the development/demonstration phase. The biggest hurdle has been development of a feasible system for cleaning landfill gas prior to use in the fuel cell.

Fuel cells create energy by combining hydrogen (obtained from a fuel source such as landfill gas) and oxygen (supplied from the air) in an electrochemical reaction. Electricity is produced continuously, as long as there is a supply of fuel and air, at high efficiencies (e.g., 50 percent or more). There are three types of fuel cells suitable for power generation: phosphoric acid fuel cells; molten carbonate fuel cells; and solid oxide fuel cells. Phosphoric acid fuel cells (PAFC), which use hydrogen gas or reformed methanol as fuel sources, are the closest to commercialization for a landfill gas application. A 200-kW PAFC plant has been tested by the EPA at the Penrose

Landfill in Sun Valley, California [Swanekamp, 1995].⁵ Northeast Utilities installed the test unit at the Flanders Road Landfill in Groton, Connecticut in late 1995, and operation at the site began in June, 1996. Connecticut Light & Power, a subsidiary of Northeast Utilities, is operating and maintaining the test unit, and using 140 kW of the power it produces. In addition, the Department of Energy is working to demonstrate molten carbonate fuel cell technology for landfill gas applications.

Option 3: Upgrade to High-Btu Gas

A third project option is to upgrade the landfill gas to a high-Btu product for injection into a natural gas pipeline. Because of the relatively high capital cost of this option, it may be cost-effective only for those landfills with substantial recoverable gas (i.e., at least 4 million cfd [Maxwell, 1990]). This application requires relatively extensive treatment of the gas to remove CO₂ and impurities. In addition, gas companies require that gas injections into their pipeline systems conform with strict quality specifications, which can impose additional quality control and compression requirements. However, this may be an attractive option for some landfill owners, since it is possible to utilize all gas that is recovered.

Upgraded gas will require significant compression in order to conform with the pipeline pressure at the interconnect point. High pressure lines may require pressures of as much as 300 to 500 pounds per square inch (psig), while low and medium-pressure lines may require 10 to 30 psig.

Option 4: Alternative Uses

Other landfill gas utilization options include on-site use of the gas (which may be particularly appropriate for small landfills), heating greenhouses, producing carbon dioxide and other niche applications, or use as vehicle fuel, such as compressed natural gas and methanol. On-site and niche applications are in limited use. Vehicle fuel uses are currently in the commercialization phase, with only a few projects in place (Box 3.5 highlights two of these projects). These and other emerging applications must be evaluated on a case-by-case basis. Their likelihood of success at a particular landfill depends on site-specific factors such as

⁵ In July, 1996, Ron Spiegel of EPA's Office of Research and Development, was named a finalist for the 1996 Discover Magazine awards for his work in applying fuel cell technology to landfill gas.

the needs of the landfill, its size, and the quality of the gas. Regulatory developments, the goals of the owner/operator (e.g., an alternative, low emissions fuel source may be attractive for a municipality's fleet), and the needs of potential customers are also important. Because these applications are not fully commercial, they are not discussed extensively in this handbook.

Box 3.1 Landfill Gas as a Vehicle Fuel

CNG Application

The Los Angeles County Sanitation District's Puente Hills Landfill has succeeded in turning landfill gas into a clean vehicle fuel. The Sanitation District has installed a compressed landfill gas fueling station on-site and has converted a Sierra pickup truck, a Hercules water truck and the first of four garbage trucks to run on the compressed gas. This project has eliminated the need to flare excess gas from the landfill, and has reduced vehicle emissions at the same time.

Methanol Production

Using \$500,000 in funding from the South Coast Air Quality Management District of California, TeraMeth Industries, Inc. modified its proprietary technology to produce Grade A methanol from landfill gas. Methanol (the critical ingredient in MTBE for federal and state reformulated gasoline requirements) is produced by first creating a synthesis gas which is then fed into a catalyst.

TeraMeth's California facility will produce 16,667 gallons per day of methanol when it begins operation in 1997 [Bonny, 1996].

3.2 CHOOSING AN ENERGY RECOVERY OPTION

The primary factor in choosing the right project configuration for a given landfill is the cost of the energy recovered. In general, sale of medium-Btu gas to a nearby

customer, which requires minimal gas processing and typically is tied to a retail gas rate rather than an electric utility buyback rate, is the simplest and most cost-effective option. If a suitable customer is nearby and willing to purchase the gas, this option should be thoroughly examined. For many landfills, however, power production is and will continue to be the best available option. This section therefore focuses on the power production options.

At the foundation of any cost estimation is the expected amount of landfill gas that will be available for energy recovery. For initial assessments, an estimate of landfill gas quantity is all that is needed to estimate power potential. Assumptions regarding the Btu value of the gas, the efficiency of the generator, and the amount of downtime can then be used to convert the gas volume into power potential, as shown in Box 3.6.

Box 3.1 Converting Gas Flow Rates into Power Potential

1) Estimate the **Gross Power Generation Potential**. This is the installed power generation capacity that the gas flow can support. It does not account for parasitic loads from auxiliary systems and equipment, or for system down time. **Gross Power Generation Potential** is estimated using the following formula:

$$\text{kW} = \text{Landfill Gas Flow (cf/d)} \times \text{Energy Content (Btu/cf)} \times 1/\text{Heat Rate (kWh/Btu)} \times 1 \text{ d}/24 \text{ hr}$$

where:

- Landfill Gas Flow is the net quantity of landfill gas per day that is captured by the collection system, processed, and delivered to the power generation equipment (usually 75% to 85% of the total gas produced in the landfill)
- Energy Content of landfill gas is approximately 500 Btu per cubic foot
- Example Heat Rates are:
12,000 Btu/kWh for IC Engines and combustion turbines (above 5 MW); and
8,500 Btu/kWh for combined-cycle combustion turbines.

2) Estimate the **Net Power Generation Potential**. This is the Gross Power Generation Potential less parasitic loads from compressors and other auxiliary equipment. Parasitic loads are estimated to range from 2% for IC engines to 6% or higher for combustion turbines.

3) Estimate the **Annual Capacity Factor**. This is the share of hours in a year that the power generating equipment is producing electricity at its rated capacity. Typical Annual Capacity Factors for landfill gas projects range between 80% and 95% and are based upon generator outage rates (4% to 10% of annual hours), landfill gas availability, and plant design. The assumed Annual Capacity Factor in the equation found in 4) is 90%. (See Table 3-2).

4) Estimate the **Annual Electricity Generated**. This is the amount of electricity generated per year, measured in kWh, taking into account likely energy recovery equipment downtime. It is calculated by multiplying the Net Power Generation Potential by the number of operational hours in a year. Annual operational hours

This section compares the power production options on a unit cost basis for typical landfills with 1, 5, and 10 million tons of waste in place.⁶ In addition to the landfill size and its associated gas production, a number of other factors are also important to project costs. These include: project scope (i.e., whether both a collection system and an energy recovery

⁶The amount of landfill gas associated with these landfill sizes was estimated using an EPA model that falls within the range of methods A and B presented in Chapter 2.

system are required or only an energy recovery system); financing method; and available incentives to encourage landfill gas energy recovery. Each of these factors is discussed briefly below.

- **Project Scope:** Project scope depends upon the extent of landfill gas collection activities already underway (or planned) at the landfill, and it can have a significant impact on project costs. There are two typical landfill project scopes:
 - **Total Project:** refers to those projects at landfills with no current gas collection or energy recovery. For these projects, the entire project (including both gas collection and energy recovery systems) must be installed and the full costs must be recovered through the revenues from energy sales; and
 - **Energy Recovery Project:** refers to projects at landfills where gas collection systems have already been (or will soon be) installed. At these landfills, the costs associated with the collection system are sunk costs, and the only costs that need to be taken into consideration for the economic analysis are those associated with the additional equipment (i.e., the energy conversion system).
- **Financing Method:** As discussed in Chapter 6, there are many different financing methods available for landfill projects. The most common financing methods are private equity financing, "project finance" using a combination of debt and equity, and municipal bond finance, where public organizations issue bonds to raise project debt. The choice of financing method can have a significant impact on project costs; in general, municipal bond financing is much less expensive than financing with commercial debt and/or equity.

- **Available Incentives:** Because of the importance of encouraging landfill gas energy recovery, a number of federal, state and local incentives are available to these projects. The most important incentives are likely to be the IRS Section 29 tax credit, which may be available to private project developers, and the Department of Energy's Renewable Energy Production Incentive (REPI), which is available to public project developers. Both of these incentives can significantly improve project economics. The Section 29 tax credit is currently worth about \$0.9 to \$1.3/kWh, depending upon the efficiency of the generating equipment. The REPI is worth up to \$1.5/kWh.

The cost per kilowatt hour for each power generation option -- IC engine, combustion turbine, or steam turbine -- will vary with the size of the landfill and these other factors, as shown in Table 3-3. Table 3-3 can be used to estimate the likely costs of a power generation project in the following way:

1. Determine whether it will be necessary to install both a gas collection system and an energy recovery system at the landfill, or only an energy recovery system. If both systems are required, examine the "Total Project" entries; if only an energy system is required, examine the "Energy Recovery Project Only" entries.
2. Determine whether municipal or private financing will be used. If the landfill is owned by a municipality, it is possible that municipal bonds can be issued to cover costs; otherwise, private financing will likely be required.
3. Determine whether financial incentives may be available. If the project will be developed by a private developer and the gas sold to a third-party, Section 29 tax credits may be available. Public or non-profit landfill owners or developers, in contrast, may be eligible for the REPI program.
4. Determine the likely project size based on the amount of waste in place at the landfill.

Making these four decisions will enable a landfill owner/operator to determine likely power production costs for a range of generating technologies. In many cases, the lowest cost generating option will be selected. In some cases, however, it may be necessary to select a higher cost option due to other important considerations. IC engines

may not be the best technology choice in certain areas, for example, due to their higher NO_x emissions as compared to turbines.

As Table 3-3 illustrates, the estimated costs of power production can vary substantially depending on the factors presented above. At the high end, costs for a "Total Project" financed with private finance and unable to obtain any incentives could range from \$7.4 to \$7.9 per kWh for a 1 million ton landfill. The availability of municipal financing could reduce these costs by about \$0.8 per kWh and developing an "Energy Recovery System Only" project could save approximately \$2.5 per kWh. The lowest cost scenario--an "Energy Recovery System Only" project built with municipal financing and obtaining available incentives--has estimated costs ranging from \$2.8 to \$4.0 per kWh, which is less than half of the high cost case.

The same phenomenon is observed at the larger 5 and 10 million ton landfills. On the high end, "Total Project" costs at a 5 million ton landfill are estimated to range from \$6.0 to \$6.5 per kWh. This same project, implemented with municipal financing and available incentives, however, could cost only \$4.0 to \$4.3 per kWh. If the landfill already has (or plans to install) a gas collection system, the "Energy Recovery System Only" costs could be as low as \$2.7 per kWh.

At the 10 million ton landfill, high end "Total Project" costs of \$5.6 to \$5.9 per kWh drop to \$2.3 to \$2.9 per kWh for an "Energy Recovery System Only" project with municipal bond financing and incentives. Interestingly, at this size the CT is more cost-effective than IC engine. In addition, the effects of economies of scale are evident, as the costs of similar projects at a 10 million ton landfill are an average of 20 to 30 percent lower than the 1 million ton landfill and 5 to 15 percent lower than the 5 million ton landfill.

It is important to recognize that the cost estimates presented here are rough estimates developed using assumptions related to "typical" landfills. Conditions at any particular site could be quite different and these site-specific conditions must be fully accounted for when developing detailed cost estimates for specific projects.

Part II of this handbook discusses in more detail the major steps involved in the development of a landfill gas energy recovery project, from estimating expenses and revenues to constructing and operating the project. In addition, EPA is developing a simple financial model that landfill owner/operators and others can use to estimate

project costs and run sensitivity analyses. To obtain a copy of this model when it becomes available, call the EPA Landfill Methane Outreach Program Hotline at 1-888-STAR-YES.

Table 3-1 Estimated 1996 Costs of Electricity

	IC Engine		Combustion Turbine		Combined Cycle CT	
	Municipal Financing	Private Financing	Municipal Financing	Private Financing	Municipal Financing	Private Financing
Total Project without Financial Incentives (¢/kWh)						
1 Million	6.7	7.4	7.0	7.9	NA	NA
5 Million	5.5	6.0	5.6	6.2	5.8	6.5
10 Million	5.2	5.8	5.0	5.6	5.3	5.9
Total Project <i>with</i> Financial Incentives (¢/kWh)						
1 Million	5.2	6.1	5.5	6.6	NA	NA
5 Million	4.0	4.7	4.1	4.9	4.3	5.6
10 Million	3.7	4.5	3.5	4.3	3.8	5.0
Energy Recovery System Only <i>without</i> Financial Incentives (¢/kWh)						
1 Million	4.3	4.8	4.7	5.3	N.A.	N.A.
5 Million	4.2	4.6	4.2	4.7	4.7	5.3
10 Million	4.1	4.5	3.8	4.2	4.3	4.8
Energy Recovery System Only <i>with</i> Financial Incentives (¢/kWh)						
1 Million	2.8	3.5	3.2	4.0	NA	NA
5 Million	2.7	3.3	2.7	3.4	3.4	4.4
10 Million	2.6	3.2	2.3	2.9	2.9	3.9

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4. INTRODUCTION TO PART II: DETAILED ASSESSMENT OF PROJECT OPTIONS

Once the landfill owner/operator has determined that an energy recovery project is right for a particular landfill, and has made a preliminary assessment of the project options, he or she must conduct a more detailed assessment of the options, considering cost, financing, project structure, and other aspects of project development. This section contains information on each step in the assessment of project options, organized into the following chapters:

- Chapter 5: Evaluating Project Economics
- Chapter 6: Assessing Financing Options
- Chapter 7: Selecting a Project Development Partner
- Chapter 8: Winning/Negotiating an Energy Sales Contract
- Chapter 9: Obtaining Project Permits and Approvals
- Chapter 10: Contracting for EPC and O&M Services

Each chapter contains the basic information--illustrated throughout with examples--needed to conduct one step in the project assessment process. By reviewing each chapter with a particular landfill in mind, an owner/operator can develop a solid understanding of the most cost-effective and appropriate options and project structure.

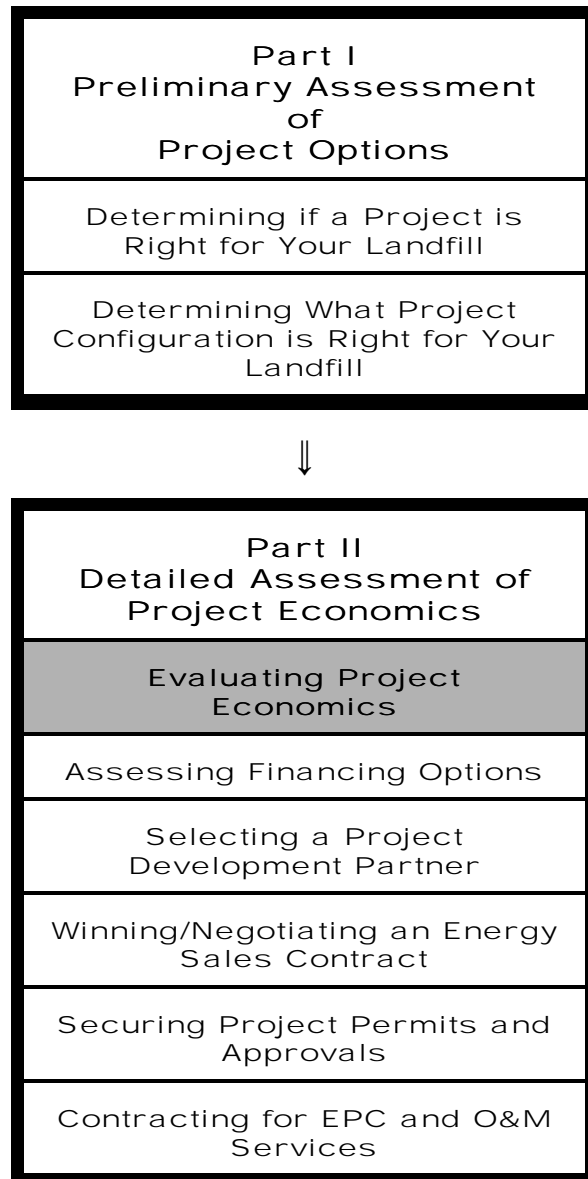
While this handbook provides valuable information to assist the owner/operator in evaluating choices and proposals, it does not serve as a technical guide to project development. The owner/operator may wish to consult a landfill gas energy recovery expert before beginning the development process.

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5. EVALUATING PROJECT ECONOMICS

After the available quantity of landfill gas has been estimated and a preliminary assessment of project options has been completed, the next step in developing a landfill gas energy recovery project is a detailed economic assessment of converting landfill gas into a marketable energy product. The economics of a landfill gas-to-energy project depend on a number of factors, including landfill gas quantity, local energy prices, and equipment choice. This chapter presents a methodology for evaluating project economics, and shows sample economic evaluations for the principal energy recovery options. Once economic feasibility has been determined, the cost and financial performance data from the economic analysis can be carried forward to the assessment of financing options, partner selection, and negotiation of energy sales and equipment contracts, which are discussed in subsequent chapters.

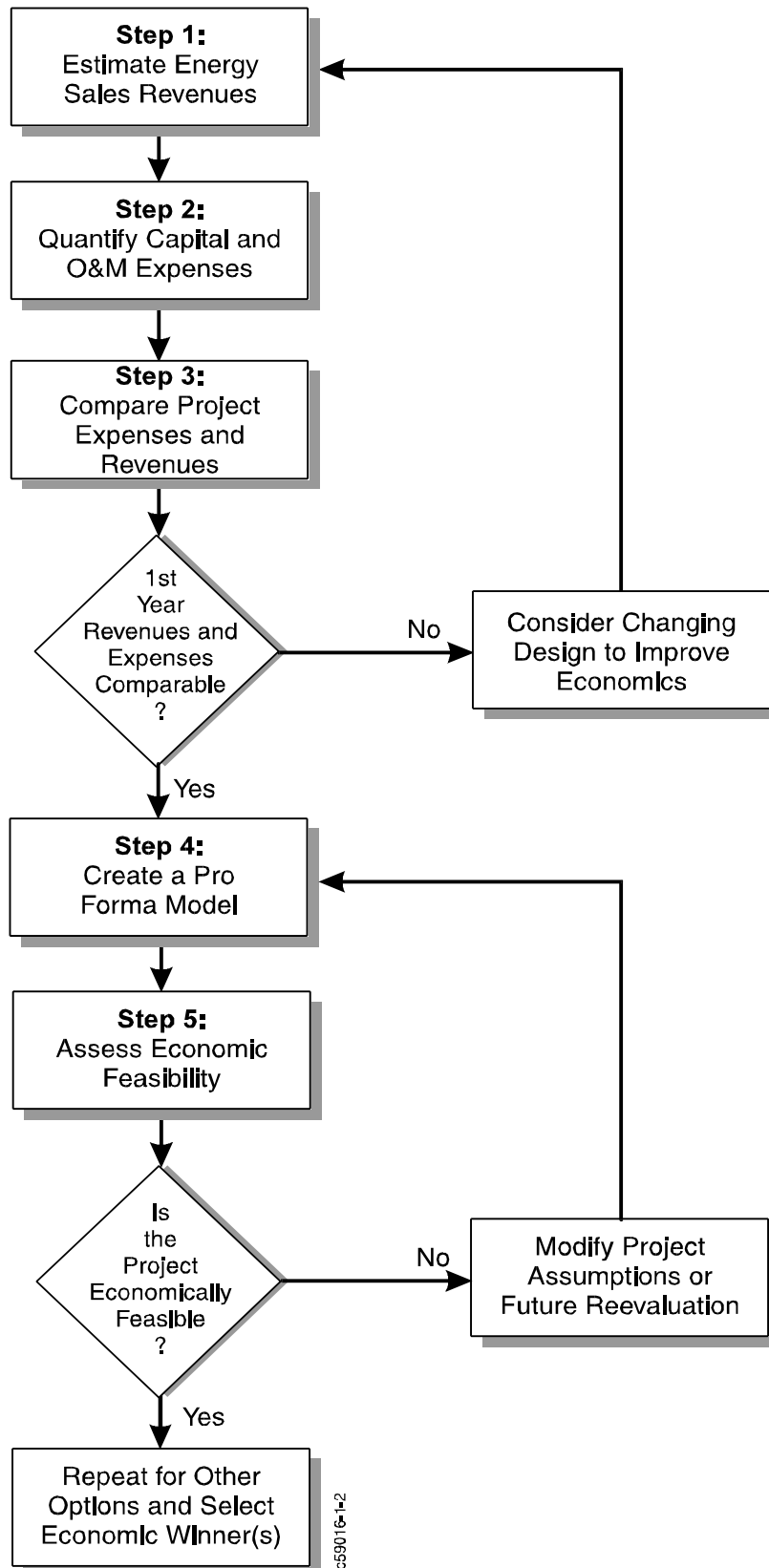
The Project Development Process



5.1 ECONOMIC EVALUATION PROCESS

An economic evaluation of a potential energy recovery project involves comparing the expenses of a particular project with the revenues that it is likely to receive. Figure 5.1

Figure 5-1 The Economic Evaluation Process



outlines the basic steps of the economic evaluation of energy recovery projects, and these steps are described in more detail below.

- Step 1. Estimate Energy Sales Revenues - Energy sales revenues include any cash that flows to the project from sales of electricity, steam, gas, or other derived products. Potential markets for energy products include electric utilities, municipal utilities, industrial plants, commercial or public facilities, and fuel companies. Revenues to the landfill gas energy recovery project are usually calculated based on the estimated quantity of energy delivered and the contract prices paid by the customer.
- Step 2. Quantify Capital and O&M Expenses - This step involves quantifying the capital costs and operation and maintenance (O&M) costs, plus in some cases landfill gas royalties and/or fees. Capital costs include not only the initial cost of the equipment, but also installation costs, debt service, owner's costs,

and returns on equity. Many of these costs vary with site-specific characteristics of the landfill.

- Step 3. Compare Project Expenses and Revenues - Once the estimates of the project's expenses and revenues have been made, an initial assessment of project economics can be made by checking to see if the first-year expenses and revenues are roughly equivalent. If they are comparable in the first year of project operation, then further economic evaluation is warranted. If not, it is usually necessary to re-examine technology, design, cost assumptions, and/or energy revenue assumptions to find ways to improve the economics.
- Step 4. Create a Pro Forma Model of Cash Flows - For a more accurate estimate of the probable lifetime economic performance of a project, the expenses and revenues should be calculated and compared on a year-by-year basis over the expected life of the project. This in-depth economic analysis, known as a pro forma, typically includes detailed calculations of project performance over time, escalation in project expenses and energy prices, financing costs, and tax considerations (e.g., depreciation, income tax).
- Step 5. Assess Economic Feasibility - Based on the pro forma model, the project economic feasibility can be assessed by calculating annual net cash flows, the net present value of future cash flows, and/or the owner's rate of return. These measures of financial performance are calculated over the life of the project and are the most reliable measures of economic performance. If these indicators are below the project proponent's criteria, he or she should re-examine the project for assumptions and/or options that can be modified.

If a landfill owner/operator has the opportunity to produce and sell more than one type of energy product, then the net cash flows of each option should be compared head-to-head to determine the best option. Cash flows of competing projects can be compared on an annual, net present value, and/or rate of return basis. After selecting an economic winner, the landfill owner/operator should then consider non-price factors including risks, ability to obtain financial backing, environmental performance, and reliability of assumptions. The option that produces the best financial performance while meeting the desired environmental, risk,

and operating requirements is the overall winner.

The remainder of this chapter discusses the process of conducting a step-by-step economic analysis for the various landfill gas energy recovery options. The economic analyses presented in this chapter provide the landfill owner/operator with basic estimates of project costs and market prices for energy products. The landfill owner/operator can use the concepts presented to create his or her own economic analysis.

Example Landfill

Throughout this chapter, the key aspects of the economic evaluation process are illustrated with examples. These examples are based on a hypothetical landfill with 5 million metric tons of waste in place and a net sustainable landfill gas production level of 2,988 mcf/day. Box 5.1 presents the operating and cost assumptions that are used consistently in this chapter.

Appendix A contains the supporting performance and cost calculations for the 5 million metric ton example, and for two other landfill sizes--1 million metric tons and 10 million metric tons. Appendix A also contains sample cost calculations for a medium-Btu gas sales project.

5.2 POWER GENERATION/COGENERATION

The opportunity to collect landfill gas and burn it to produce electric power is available to most landfill owners. Whether or not this option is economically feasible depends largely on local electricity prices, which vary dramatically across regions of the country. Other important factors include access to electricity purchasers, landfill gas volume, and technology selection. This section presents a sample economic analysis - using the five steps outlined above - for a landfill gas power generation project.

5.2.1 Step 1: Estimate Energy Sales Revenues

A landfill gas power project can have one or more sources of revenue, depending on whether it produces just electricity or also cogenerates steam and/or other thermal energy. An important potential source of revenue is use of a portion of the landfill gas or the derived electricity or steam to offset energy costs (e.g., natural gas, oil, electricity) at its own facilities. The savings that are achieved by offsetting energy purchases can be counted as a type of revenue. The following paragraphs describe the principal sources of revenue for power projects.

Electric Buyback Rate

The economic factor that will usually have the greatest impact on a power project's economic feasibility is the local electric utility's buyback rate (i.e., the price the utility is willing to pay for the electricity produced by a non-utility electric generator). The buyback rate reflects the utility's own avoided costs of generating electricity, incorporating the cost of building new generating capacity if needed. The costs of generating electricity, and thus buyback rates, vary considerably among utilities and regions. Factors such as fuel mix, availability of cheap hydropower, utility financial health, and reserve margins have a large influence over local electricity costs and the rate (i.e., price) at which electric utilities will buy electricity from a landfill gas project.

Box 5.1 Assumptions for 5 Million Metric Ton Landfill Example

Operating Assumptions

Waste in place:	5 million metric tons
Collection efficiency:	85%
Net sustainable LFG production:	2,988 mcf/day
LFG calculation method:	EPA Report to Congress Equation [EPA]
Electric output calculation:	$\text{kw} = (\text{cf/hr}) \times (500 \text{ Btu/cf}) / (\text{Btu/kwh})$
Electric heat rate (Btu/kwh):	12,000 for IC engine & CT
	8,500 for combined cycle
Online date:	June, 1996
Annual capacity factor:	80%
Annual full load operating hours:	7,008

Capital Cost Assumptions

Energy conversion system cost includes engine/generator, auxiliary equipment, interconnections, gas compressor, and construction costs.

LFG collection system includes collection wells, blower, and flare system.

Engineering costs = 5% of installed equipment costs.

Soft costs include owners' costs (e.g., legal, permitting, insurance, taxes), escalation during construction, interest during construction, and contingency.

Incremental Capital Requirement = Total Costs - LFG Collection System Costs.

Cost of Electricity

Cost of Electricity = Capital component + O&M component + Royalty

Capital Charge Rate assumptions:

<u>Project Finance Case</u>	<u>Muni</u>
Finance Case	

- | | |
|------------------------|-----------|
| • 20 year project life | • 20 year |
|------------------------|-----------|

U.S. electric utilities are currently required by the Public Utility Regulatory Policies Act (PURPA) to buy electricity from qualifying facilities, which include small power producers and cogenerators. Small power producers are defined as electric generating facilities that produce up to 80 MW and use mostly non-fossil fuels. Landfill gas energy recovery facilities are eligible to be classified under PURPA as small power producers. PURPA dictates that electric utilities must buy electricity at a rate no higher than the utility's "avoided cost," which is the cost that the utility would pay to generate the next increment of electricity using its own resources.

Avoided costs are typically filed with the state utility regulators on a regular basis, and some utilities publish buyback tariffs, accompanied by standard offer contracts, based on their avoided cost. (More information on standard offer contracts is provided in Chapter 8.) Utility buyback tariffs regularly include an avoided energy price, and some utilities also pay an additional component for their avoided capacity costs. The energy price component is based

on the utility's fuel costs and operation and maintenance costs, which may vary depending on the time of day or year. The capacity price component is usually fixed, based on the utility's cost of building or buying additional capacity. Only utilities that actually need additional generating capacity will typically offer a capacity price component.

The avoided energy price component alone may not be enough to support a landfill gas power project. In these cases, landfill gas power project developers must seek electric utility customers that need additional capacity and are offering a capacity price component as well. Some utilities might offer a premium for renewable energy or environmentally beneficial projects such as landfill gas energy recovery. In some cases the utility's published tariff will be acceptable, but more often the project developer must attempt to negotiate a more favorable rate. (Chapter 8 discusses the different avenues to obtaining power sales contracts.)

In addition to possible sales to an electric utility, state regulators may allow direct electricity sales to one or more local customers. These sales are usually conditioned on the fact that they are limited to a number of contiguous neighbors. If such sales are allowed, the landfill gas power project must negotiate a rate with the customer. It is usually necessary to offer the customer an electricity rate that provides a discount over the rate currently paid to the local utility, unless the project is offering something that the local utility does not, such as higher reliability. Since retail electric rates are typically higher than the buyback rates offered, this type of arrangement can be very attractive to the seller and the buyer.

Historically, landfill gas power projects have received electric buyback rates ranging from \$2/kWh to \$10/kWh, averaging about \$6/kWh. However, newer projects generally report receiving only \$3/kWh to \$4/kWh [EPA, 1993]. The chief reasons for lower rates in recent years are a slowdown in the rate of electric demand growth, and an abundance of generating capacity in some parts of the country (e.g., Southwest, New England). Generally, significant economic potential for landfill gas power projects exists where electric buyback rates are above \$4/kWh, although technology improvements, emerging applications, and requirements to recover landfill gas for environmental reasons are increasingly making projects viable at rates below \$4/kWh [EPA, 1993].

Displacement of On-Site Energy Purchases

Box 5.1 Displacement of Energy Purchases at the Prince George's County Correctional Complex

The Brown Station Road Landfill (4 million tons waste in place and growing) in Prince George's County, Maryland provides landfill gas to meet the electrical and heating needs of the County Correctional Complex. This energy recovery system generates electricity using three 850-kw IC engine generators and also delivers medium-Btu gas to two conventional boilers located at the correctional complex. The three electric generators provide almost all of the correctional complex's electrical needs; excess electricity generated by the project is sold to the local electric utility (PEPCO). The boilers, which were originally designed to burn No. 2 fuel oil or natural gas, were adapted for landfill gas fuel and provide heat and hot water for the correctional complex. The project configuration was selected from among several options based on an economic comparison which examined lifetime costs and revenue to the county.

The project displaces most of the county's electricity and heating fuel costs associated with the correctional complex. The county estimates that the gross benefits are about \$1.2 million per year in energy cost savings [Augenstein and Pacey, 1992].

It may be practical to use a portion of the generated electricity to displace some or all of the electricity purchases at commonly-owned facilities near the project site. For example, for a county-owned landfill, opportunities for displacement savings may include energy use at county office buildings, maintenance shops, water treatment plants, community centers, and correctional facilities. Displacement savings are calculated by determining the amount of on-site electricity usage that can be met by the energy project, then determining the cost of that electricity usage, based on the current retail rates or recent electric bills. The retail rates paid by the landfill owner/operator to the utility are typically higher than the buyback rate offered by the utility to purchase the power.

Displacement savings may also be achieved when the landfill owner/operator can use a portion of the landfill gas produced to offset natural gas or oil purchases at nearby facilities under the same ownership. The economic

incentive for the owner/operator to try and offset these fuel costs will mainly be determined by the landfill's proximity to facilities that use natural gas or oil to meet process or heating needs. The savings possible from these offsets will depend on the existing fuel costs of the facilities and the amount of landfill gas that can be used by the facilities. Box 5.2 describes a landfill gas energy recovery project that displaces boiler fuel purchases and generates electricity for a Prince George's County, Maryland facility.

Thermal Energy Revenues

Landfill gas energy recovery projects can generate thermal energy such as steam or chilled water for use in nearby industrial plants or commercial facilities (e.g., hospitals, office buildings, hotels, universities). The economic incentive to cogenerate steam and other forms of thermal energy along with electricity using a cogeneration configuration is determined mainly by the potential customer's existing costs of generating thermal energy, and by the project's proximity to the customers. Typical steam costs range from \$1.5 per million Btu (MMBtu) to \$6/MMBtu, depending on the existing fuel and technology being used. Steam generation from waste fuels, wood, and sometimes coal can achieve costs at the low end of this range, while gas- and oil-fired steam is usually more expensive. Landfill project owner/developers should expect to offer some discount, often on the order of 5% to 30%, over a potential customer's current steam cost in order to be attractive.

Sample Calculation of First Year Revenues

For the hypothetical 5 million metric ton landfill described in Box 5.1, revenues are assumed to be created by generating electricity for: (1) sale to the local electric utility; and (2) displacement of retail electric purchases at a municipal office building. This example assumes that the electric buyback rate in 1996 is \$4.8/kWh. It also assumes that there is a nearby office building, owned by the landfill owner/operator, that consumes 3 million kWh per year at a retail rate of \$5.9/kWh in 1996. Table 5-1

Table 5-1 Estimated First Year Power Project
Revenues at Example Landfill

presents a calculation of first-year revenues, which range from \$1.7 million for an IC engine system to \$2.3 million for a combined-cycle CT system. The combined-cycle CT produces more revenues than the other

technologies because it generates more electricity, but the Step 2 analysis will show that the combined-cycle CT is also more expensive to build. The first-year revenues amount to \$4.9/kWh for all three technologies on a per kWh basis, calculated by dividing the annual revenues by the total kWh generated and sold. In Step 3 this revenue estimate will be compared against the cost of generating electricity from landfill gas, which varies significantly among the technologies as described in the next section.

5.2.2 Step 2: Quantify Capital and O&M Expenses

To evaluate the economic feasibility of a landfill gas power project, the project expenses must be subtracted from revenues to determine potential gains (or losses). The chief project expenses are the amortization of up-front capital costs and the annual O&M expenses. Some projects have other expenses such as payment of fees or royalties for landfill gas rights. The following sections describe the different categories of project expenses.

Capital Costs

The total capital requirement for a landfill gas power project includes the costs of the major equipment (e.g., engine, CT), as well as the costs associated with the auxiliary equipment, construction, emissions controls, interconnections, gas compression and treatment, engineering, and "soft costs." Soft costs typically include up-front owner's costs (e.g., development staff, legal, permitting, insurance, property tax), escalation during construction, interest during construction, and owner's contingency, all of which are real costs incurred prior to and during the construction process.

The costs of the landfill gas collection system (e.g., equipment, installation, soft costs) can be excluded from the economic analysis if the collection system is either already in place or required by air emissions regulations. The energy recovery system can then be evaluated using an incremental cost approach. Under the incremental cost approach, the collection system costs are not included because these are sunk costs that would be incurred whether the recovered landfill gas is put to use or just flared. In the 5 million metric ton landfill example, the total cost includes the costs associated with the energy conversion system plus the landfill gas collection system, while the incremental cost does not include the capital or O&M costs associated with the landfill gas collection system.

Capital costs for landfill gas power projects vary widely depending on landfill size, conversion technology, and project design. Table 5-2 presents the estimated capital costs of landfill energy recovery systems for landfills with 1, 5, and 10 million metric tons of waste in place. For these hypothetical energy recovery projects beginning operation in 1996, the total capital requirement is estimated to range between \$1,595/kW and \$2,423/kW, and the incremental capital requirement is estimated to range between \$1,109/kW and \$1,691/kW¹. These cost data are expressed in as-spent dollars, which means that equipment cost escalation (e.g., inflation) prior to and during construction is included in the cost estimate. As the cost data show, the capital cost per kW generated (\$/kW) generally decreases with increasing project size, owing mainly to economies of scale, particularly for the CT-based technologies.

In the example cost calculation for the 5 million metric ton landfill producing about 3 million cf of landfill gas per day in 1996, the total capital requirement ranges from \$1,675/kW for an IC engine system to \$2,025/kW for a combined-cycle CT system, including the cost of the gas collection system (see Table 5-3). On an incremental basis, the capital requirement ranges from \$1,177/kW for the IC engine to \$1,658/kW for the combined-cycle CT. These costs are in as-spent dollars, reflecting a June 1996 on-line date. A boiler/steam turbine system would not be economically competitive at this size, but boiler/steam turbine system costs would probably become competitive at larger gas flow rates above roughly 5 to 7 million cf/day.

Although capital cost is the major determinant of the cost of generating electricity from landfill gas projects, the technology with the lowest capital cost is not always the choice. A good example is the 10 million metric ton landfill case presented in Appendix A. In that case, the IC engine has the lowest capital cost, but after O&M and royalty expenses are taken into account, the CT option yields the lowest cost of electricity. Other factors such as reliability and emissions also should be considered when deciding among technologies (see Part I for more on technology

¹ Not included in the capital cost data are preliminary project development expenses, the major component of which is landfill gas quantity testing. The most reliable method of testing is to drill test wells and conduct a pump test. Test wells typically cost between \$5,000 and \$10,000 per well [Smithberger, 1994; Merry, 1994], and the number of wells required to accurately predict landfill gas quantity will depend on a number of factors such as landfill size and waste homogeneity.

issues).

O&M Expenses

The O&M expenses vary considerably among projects due to different equipment types and gas treatment processes. Typically, O&M expenses include both fixed and variable expenses, as described in Box 5.3. Fixed O&M expenses are predictable and are not dependent on the amount of time that the project operates or the amount of electricity generated. Variable O&M expenses are usually dependent on the amount of time that the project operates, which can be measured by the amount of electricity (i.e., kWh) produced.

The total generator system O&M costs for IC engines are about \$1.8/kWh in 1996 dollars [EPA, 1993]. The O&M costs associated with the gas collection system are about \$0.5/kWh [EPA, 1993]. The O&M costs for CT-based systems are generally lower than those for IC engine-based projects [Wolfe and Maxwell].

Royalties/Gas Payments

The project developer may also need to pay for the gas received in the form of royalty payments to the owner of the gas rights and/or as gas payments to a gas company that collects and delivers the landfill gas. Royalties can be viewed as compensation for gas rights or as a financial incentive for allowing the project to be developed. Historically, power project owners have paid royalties to landfill owners equal to 10% to 12.5% of project revenues [Jansen, 1992; Augenstein and Pacey, 1992]. In recent years, the tightening of project financial margins has caused a reduction or elimination of pure royalty payments to landfill owner/operators. Royalties that are still paid are usually paid by the gas company.

Gas payments are made by generation companies or other end users for delivery of the gas. Gas payments are necessary in order for the project to take advantage of certain tax credits, because the gas must be sold to an unrelated party (e.g., power generator, industrial user). Tax credits are discussed in more detail later in this chapter.

Table 5-1 Estimated Power Project Capital Costs for Three Landfill Sizes

Table 5-1 Estimated Power Project Capital Costs at
Example Landfill

Box 5.1 Classification of O&M Expenses

O&M expenses include both fixed and variable expenses, as shown below.

<u>Fixed O&M expenses</u>	<u>Variable O&M</u>
<u>expenses</u>	
Labor	Periodic
maintenance and overhauls	
Property taxes	Water
Insurance	Consumables (e.g.,
lubricating oil, Administrative expenses	
hydraulic fluid, filters)	
Spare parts	
Fees	
Emissions offsets	

The distinction between fixed and variable expenses is important, because fixed O&M expenses are incurred regardless of the amount of electricity generated.

The 5 million metric ton landfill example includes an annual royalty payment/gas payment equal to about 10% of revenues. Including a royalty/gas expense demonstrates the economic effect that royalties have; namely, they make landfill gas projects more expensive. In the example, paying the royalty increases costs by ¢0.5/kWh, which could make the difference between an economically attractive project and an unattractive project. In the future, landfill owner/operators may have additional incentive to forego royalty payments because of the environmental benefit of a landfill gas recovery project.

Estimating the Cost of Electricity

The cost of generating electricity (¢/kWh) from a landfill gas power project is equivalent to the sum of capital expenses, O&M expenses, and royalty/gas expenses (if any), divided by the kWh of electricity delivered. Estimating this cost has two steps:

- (1) Amortize capital costs and divide by the annual kWh produced; and
- (2) Add O&M and royalty expenses.

Each of these steps is described below and illustrated with

an example.

Step 1: Amortize Capital Costs: Capital costs are commonly "levelized," or amortized in equal annual amounts over the economic life of the project (i.e., over the period that the project will generate revenues). If the productive landfill life is 20 years, then a typical term for the levelized capital cost calculation would be 20 years. For the purposes of economic analysis, the capital costs are often amortized using a capital charge rate (CCR). A CCR is used to convert the installed cost into a levelized capital cost that can be charged to the project in each year of the project life. The CCR is the levelized percentage of the total capital that must be recovered in each year to cover:

- return of equity;
- return on equity;
- interest on debt;
- depreciation;
- general and administrative expenses;
- property tax; and
- income tax.

The CCR can be calculated by estimating annual interest and return on equity payments on the outstanding loan value over the life of the project (similar to a home mortgage) and adding annual amounts for depreciation, expenses, and taxes. The main variables in the CCR calculation are the debt/equity ratio and interest rates. The CCR for a privately financed landfill gas-to-energy project will be higher than the CCR for a project financed with municipal bonds (More detailed information regarding CCRs under different financing scenarios is contained in Chapter 6.):

- Project Finance Case: A CCR of approximately 0.136 would result in the case where a project is financed with a debt/equity ratio of 80/20, a nominal interest rate on debt of 9%,² an after tax return on equity of 15%, and a 10-year tax depreciation. (To take advantage of 10-year

² Interest rates are determined by the prevailing rate indicators (e.g., U.S. treasuries, prime rate, LIBOR) and a host of project- and lender-specific factors. When this document was written, rates for nonrecourse debt for a "strong" landfill gas project ranged from 9% to 9.8%. [Seifullin, 1995; DePrinzio, 1995] Increasing interest rates by 1% would cause the cost of electricity to increase by 2% to 3%.

depreciation, the project life is assumed to be just under 20 years.)³

- **Municipal Bond Finance Case:** Thus, a CCR of approximately 0.111 would result from the case where a project is financed with 100% municipal tax-exempt bonds that have a 6.5% interest rate.

To obtain a levelized capital cost (LCC) in ¢/kWh units, the annual cost calculated as described above must be divided by the expected operating hours per year as follows:

$$\text{LCC} = \text{Installed Cost} \times \text{CCR} / (\text{CF} \times \text{Hours per Year}) \times (\text{¢100/\$}) \quad (\text{Eq. 5.1})$$

where:

LCC	=	levelized capital cost (¢/kWh)
Installed Cost	=	total or incremental capital requirement (\$/kW)
CCR	=	capital charge rate
CF	=	annual average capacity factor
Hours per year	=	8,760

Using the 5 million metric ton landfill example, the levelized capital cost for the IC engine option would be ¢3.2/kWh, calculated as follows using an 80% capacity factor⁴:

$$\text{¢3.2/kWh} = (\$1,675/\text{kW} \times 0.136) / (80\% \times 8760 \text{ hrs}) \times (\text{¢100/\$})$$

If the project were financed with 100% tax-exempt municipal bonds (CCR = 0.111), the levelized capital cost would be ¢2.7/kWh.

Step 2: Add O&M Expenses: This step is straightforward--add the estimated O&M expenses and royalty expenses (if any) to the capital expense to get the total cost of electricity.

³ Landfill gas energy recovery projects appear to be eligible to use 10-year depreciation for income tax purposes. [Jansen, 1992; Mumford and Lacher, 1993] Property with a life of 16 years or more, but less than 20 years, can use the 10-year Modified Accelerated Cost Recovery System (MACRS) depreciation schedule. [RIA, 1992]

⁴ See Box 3.6 in Chapter 3 for a discussion of capacity factors.

Based on the capital, O&M, and royalty expenses discussed above, the total first year cost of generating electricity from the 5 million metric ton landfill in 1996 are presented in Table 5-4. As the table shows, the cost of the conversion system plus the gas collection system could range from \$6.0/kWh to \$6.5/kWh

Table 5-1 Estimated Cost of Electricity Production for
Three Project Configurations at Example Landfill

if the project were financed with 80% debt and 20% equity. Financing 100% of the project costs with tax-exempt municipal bonds would achieve a cost of electricity ranging from ¢5.5/kWh to ¢5.8/kWh. The incremental cost of electricity, which excludes collection system costs, would be approximately 20% to 25% lower, or ¢4.6/kWh to ¢5.3/kWh for the project finance case, and ¢4.2/kWh to ¢4.7/kWh for the municipal bond finance case. [Note that these costs of electricity include a royalty payment of ¢0.5/kWh and do not include the effects of incentives, which could trim another ¢1/kWh or more off the electricity cost if applicable (incentives are factored into the calculation in Step 3).]

The IC engine appears at this landfill size to have a slight cost advantage over the CT and a substantial advantage over the combined-cycle CT, owing mainly to the IC engine's lower engine and gas compressor costs, and gas compressor auxiliary load. However, the IC engine loses some of its advantage because of higher O&M costs.

5.2.3 Step 3: Compare Project Expenses and Revenues

As a first cut at assessing a particular project's economics, first-year expenses and revenues are often compared to see if a project configuration warrants further analysis. At this point it is important to include any tax credits or other incentives in the economic assessment. If first-year project revenues are comparable with expenses, making sure to take into account any tax credits that are available, then it is advisable to proceed to the next step: creating a pro forma model of project cash flows. If the estimated revenues fall significantly short of the project costs, one or both of the following two options should be pursued:

- 1) Look for additional sources of revenue (e.g., on-site sales, thermal sales) or alternative customers (e.g., electric utilities, municipal utilities) that may offer a higher electricity price; and/or
- 2) Change the project configuration (e.g., size, technology, equipment vendor, energy outputs) and re-examine the economics.

Tax Credits/Incentives

Tax credits and federal incentive payments can significantly improve project economics, and help to justify an otherwise marginal project. Currently, federal tax credits listed under Section 29 of the Internal Revenue Code are available for the recovery and use of unconventional gas fuels such as landfill gas. Additionally, the "Renewable Energy Production Incentive" (REPI) program, which was mandated under the 1992 Energy Policy Act and is being implemented by the U.S. Department of Energy, provides an incentive to publicly owned facilities that generate electricity from renewable energy sources such as landfill gas. The applicability of these incentives depends on the structure of the project and the owner/operators' tax situation. Therefore, a full understanding of the tax laws and how they may be applied is critical to ensuring a project's ability to take advantage of the incentives.

Section 29: The Internal Revenue Service (IRS) Section 29 tax credit, currently due to expire in the year 2007, is available to landfill gas projects that are operating before June 30, 1998. This tax credit has been extended several times by the U.S. Congress since its initial inception, but there are no guarantees that the extensions will continue. The credit is worth \$5.83 per barrel of oil-equivalent (on a MMBtu basis) and is adjusted annually for inflation [Conversation with Tommy Thompson, U.S. Internal Revenue Service, April 1996]. The current value of the credit is \$1.001 per MMBtu [Conversation with Tommy Thompson, U.S. Internal Revenue Service, April 1996]. At full value, this converts to about 0.9¢ to 1.3¢/kWh for a typical landfill gas electricity project, depending on the efficiency of the generating equipment used.

The Section 29 tax credits apply only to landfill gas that is produced and then sold to an unrelated third party (for example, when landfill gas is sold as a medium-Btu fuel to an industrial customer) [RIA, 1992]. As a result of this stipulation, project developers may bring in or create a separate company when developing power projects in order to take advantage of the credits. Several project structures exist that would allow a landfill gas project to benefit, either directly or indirectly, from the tax credits. Three such structures are presented in Box 5.4. Depending on the structure used, the project may receive only a fraction of the value of the tax credits. For example, if a tax-paying company takes responsibility for gas collection and sells the gas to a power project, the collection company

is entitled to the Section 29 tax credits. However, if this company cannot fully use the credits, as is often the case, the company might transfer the credits to outside investors who can use them. Usually the gas collection company must "sell" the tax credits at a discounted price, leaving the collection company with as little as 60% of the full value of the tax credits.

Box 5.1 Examples of How A Project Can Be Structured to Take Advantage of Section 29 Tax Credits

Privately Owned Landfill:

Scenario One:

- The landfill owner owns and operates the gas collection system (GASCO), and sells the gas to the developer for use in the energy recovery project (GENCO).
- The GENCO is owned and operated by a developer who is unrelated to the landfill owner.

Result: The landfill owner receives gas revenues and tax credits, which can be used or sold along with the GASCO to another party.

Publicly Owned Landfill:

The following scenarios describe structures that enable a landfill owner who cannot take direct advantage of tax credits (e.g., a municipality) to benefit from the transfer of credits.

Scenario One:

- An entity (GASCO) unrelated to the landfill owner purchases the gas rights from the landfill and operates the gas collection system. It sells the gas to the energy recovery project (GENCO).
- The GENCO is owned and operated by a developer who is unrelated to the landfill owner.

Result:

The landfill owner receives a one-time payment for its gas rights, and the owner of the GASCO receives the tax credits.

Scenario Two:

- The landfill leases gas rights, for a "production fee," to an unrelated party (GASCO) who sells the gas to the energy recovery project (GENCO).
- The GENCO is owned and operated by a developer who is unrelated to the landfill owner.

Result: The landfill owner receives production payments and a share of the tax credits.

The GASCO receives the majority of the tax credits.

In many of these cases, the developer of the energy recovery project and the purchaser/lessor of the gas rights may have overlapping ownership of up to 50%.

REPI: Section 1212 of the Energy Policy Act of 1992 stipulated that a cash subsidy of 1.5¢ per kWh (adjusted annually for inflation) would be available to renewable energy power projects owned by a state or local government or nonprofit electric cooperative, that are first used during the period October 1993 through September 2003 [Federal Register, July 19, 1995]. Solar, wind, geothermal (except dry steam geothermal), and biomass (including landfill gas, but excluding municipal solid waste) projects are defined to be renewable energy projects.

The availability of funding for REPI payments is subject to annual appropriation by Congress. Approximately \$2.2 million was appropriated for the program for fiscal year 1995, and \$3 million was appropriated for 1996 [Klunder, 1995]. Payments will be made first (and on a pro rata basis if necessary) to qualified renewable energy facilities

using solar, wind, geothermal, and closed-loop biomass technologies.⁵ Payments will then be made (on a pro rata basis if necessary) to all other qualified renewable energy facilities [10 CFR, Part 451] including landfill gas-to-energy facilities. The 1995 appropriation was enough to make all approved payments.

According to the rules governing the REPI program, projects must apply annually for the payments, which may continue for up to ten years. Applications for energy produced in a fiscal year must be submitted to the Department of Energy during the period October 1 through December 31 of the following fiscal year [10 CFR Part 451].

Example Calculation of Project Cash Flow (First Year)

An estimate of first year cash flow and economic viability is obtained by subtracting the first-year expenses from revenues, and adding available tax credits/incentives. If this calculation yields an amount of zero or greater (i.e., surplus cash flow), the assumed revenues can support the project expenses, as well as meet the project's financing requirements (e.g., a 15% return on equity in the project finance case). The financing requirements are included in this analysis as part of the project expenses. A negative result indicates a cash flow shortfall, which means that expenses will not be covered or debt service requirements will not be met in the first year. Since this calculation only provides a rough indication of economic viability, the most important result is simply whether or not the calculation yields a non-negative amount.

⁵ Closed-loop biomass means any organic material from a plant which is planted exclusively for purposes of being used to generate electricity [10 CFR, Part 451].

Table 5-1 First Year Project Revenues and Expenses
for Three Project Configurations at Example Landfill

Continuing the 5 million metric ton landfill example, the assumed electric buyback rate of \$4.8/kWh would be capable of supporting various project configurations depending on the financing assumptions and the cost basis assumption, as shown in Table 5-5. As shown in the table, all three technologies are estimated to be viable on an incremental cost basis for both the project finance and municipal bond finance cases. However, on a total cost basis, only the IC engine power configuration appears viable in the project finance case. In contrast, the cost advantages of municipal bond financing (tax exempt) allows all three technologies to be viable even under a total cost basis. This analysis demonstrates that the availability of municipal bond financing has an important effect on the economic viability of the technology options.

It is clear that for the example landfill, the IC engine power configuration appears most promising at this stage of the analysis, so the analysis of this option should proceed to Step 4. Because the CT option is relatively close to the IC engine under all scenarios, it would be reasonable to carry the CT forward for further evaluation in Step 4 as well. The combined-cycle CT should only be considered if municipal bond financing is an option.

Landfill gas power project economics have the potential to improve over time, but future performance must nevertheless be carefully examined. Economics can improve, because most of the costs are fixed (e.g., capital and gas collection costs) and not subject to significant escalation over time. Only the O&M costs are expected to increase significantly. Project revenues, which are driven by buyback rates, can increase over time and should more than offset any O&M increases. However, these positive effects can be easily negated by declining gas flows in later years, because the project will have diminished revenues (see

Chapter 3 for more on project sizing).

The results of the analysis are, of course, driven by the key assumptions that affect costs and revenues, including: incentives, royalty payments, capital and O&M costs, electric buyback rate, financing method, and annual capacity factor. In this example, the full value of tax credits or subsidies contribute 0.9¢/kWh to 1.5¢/kWh to project cash flows, and all scenarios include a royalty/gas payment expense of 0.5¢/kWh.

5.2.4 Step 4: Create a Pro Forma Model of Project Cash Flows

After an initial comparison of expenses and revenues has demonstrated that a particular project configuration could be competitive (e.g., IC engine, CT), the next step is to create a pro forma model of project cash flows over the life of the project. This type of cash flow model is known as pro forma because it usually contains several standard items including a listing of financial assumptions and operating parameters, energy pricing data, calculation of annual expenses and revenues, an income statement, a cash flow statement, and financial results (see Box 5.5). An income statement usually lists the elements of project revenues and expenses, and shows a calculation of operating income, depreciation, taxes, and net book income. A cash flow statement typically shows project cash flows including pre-tax and after-tax cash flows, and distributions to project owners. Financial results include debt coverage ratios, rate of return (ROR), and net present value (NPV).

Box 5.1 The Pro Forma

The elements of a well-designed pro forma include:

- Project specifications and cost data
- Operations summary (e.g., kwh generated, Btu delivered, gas consumed)
- Financing and depreciation summary (e.g., interest rates, schedules)
- Price escalators for fuels, consumables, services, equipment
- Operating expense calculation (annual costs for royalties, fuel, O&M)
- Revenue calculation (annual revenues from sales of electricity, energy)
- Financing costs (e.g., interest and principal payments, investor's cash flow)
- Income statement (calculation of operating income, book income)
- Income tax and tax credit calculation
- Cash flow statement (e.g., pre-tax and after-tax cash flow calculations)
- Financial performance calculation (e.g., debt coverages, ROR, NPV of cash flows)

A well-designed pro forma should give the owner/developer a clear idea of project revenues, expenses, and sensitivities, and it can also serve to convince investors of project financial viability and returns. Preparing a detailed pro forma is an important step in ensuring the financial feasibility of a landfill gas-to-energy project. The pro forma model is usually created by the project developer using a computer spreadsheet format, which makes it easy to change inputs and assumptions if needed. This feature also makes the pro forma a useful tool for testing the project's economic sensitivity to alternative assumptions and options.

A pro forma will yield a much more reliable assessment of economic viability than the first-year comparison. Therefore, it is generally recommended that a pro forma be developed for all options that achieve positive or close-to-positive results in Step 3.

5.2.5 Step 5: Assess Economic Feasibility

The key financial results of a pro forma model are used to assess the economic feasibility of a power project. Economic feasibility is usually measured by indicators such as debt coverage ratios, ROR on equity, and NPV. The debt coverage ratio, which is the annual ratio of operating income to the debt service requirement, is a measure of the project's ability to meet its debt repayment requirements, and is usually expected to be in the range of 1.3 to 1.5. Lenders often view projects with debt coverage ratios below 1.3 as having a high risk of defaulting on loan repayment, which can make financing difficult. The ROR on equity and the NPV of owner's cash flows are two measures of the financial returns to the project owner. The owner's rate of return on equity ranges from approximately 12% to 18% for most types of power projects.

An acceptable owner's ROR for a particular project is a function of project risks and the owner's objectives. If the landfill owner views the project mainly as a cost-effective pollution control measure, then financial returns are not the only consideration and a ROR of 12% or less may be acceptable. Likewise, if risks have been removed because extensive testing has been done or permits are in hand, then lower RORs may be acceptable. However, if uncertainties such as unconfirmed gas flow rates or potential permitting difficulties are present, then the owner/developer may expect a higher ROR to compensate for the risks.

5.3 SALE OF MEDIUM-BTU GAS

If there is a suitable buyer nearby, direct sales of medium-Btu gas is generally the most economic recovery option, because it entails minimum processing requirements and capital costs. The suitability of a potential buyer depends largely on two considerations: (1) the buyer's proximity to the landfill and (2) the buyer's gas requirements.

The proximity of a potential customer to the landfill is critical because the cost to deliver the gas may be prohibitive if the customer is located far from the landfill. Ideally, the customer will be no further than one to two miles away. If there are no potential customers nearby, it may be possible to entice new industrial facilities to locate near the

landfill by offering a low cost fuel.⁶

The total *annual* gas or steam requirements of a potential customer are important, since they will determine whether landfill gas production rates will support the entire needs of the customer or only a portion. For example, a five million metric ton landfill could support the processing needs of a large kiln operation, while a one million metric ton landfill may only provide enough gas to supplement needs during peak periods. When evaluating the needs of a customer who will be using landfill gas in boilers to generate steam, a general rule of thumb is that approximately 10,000 pounds per hour of steam can be provided by every one million metric tons of landfill waste in place.⁷

A potential buyer's *seasonal* gas demand is also important due to the nature of landfill gas production. If a customer has only an intermittent gas load, much of the landfill gas recovered will be flared rather than sold, since landfill gas storage is not economical. A baseload gas user which uses gas on a continuous basis is usually preferred over an intermittent user, such as a facility that uses gas mainly for seasonal heating needs. It is more difficult to justify the economics of selling gas to an intermittent user, because gas sales revenues are reduced during non-heating seasons and the landfill gas must be flared or used elsewhere.

Using landfill gas as a medium-Btu fuel in boilers that create steam to meet process or space heating needs is one of the simplest and most common direct use applications. Other industrial applications include drying operations, kiln operations, and cement and asphalt production. If one of these applications provides only a seasonal market for the landfill gas, multiple uses may be combined to achieve a continuous baseload. Box 5.6 describes how one company successfully created a year-round demand for its landfill gas production by combining the demands of its asphalt manufacturing operation with its space heating needs in the winter months. Another landfill gas application that may be ideal is to provide supplemental

⁶ New industries that are searching for a suitable facility location often work through local or state economic development specialists to identify candidate sites. Therefore, educating economic development specialists about the benefits of using landfill gas as a fuel so they can offer its advantages to potential customers may be worthwhile.

⁷ This rule of thumb assumes that steam is supplied at 50 psig, saturated.

fuel to waste-to-energy plants, which are often located near landfills. For example, at the 45-MW Ridge waste-to-energy plant in Florida, landfill gas from the adjacent landfill comprises five percent of total fuel input on a heat-input basis [Swanekamp, 1994].

The economic viability of the project can be determined once a potential gas user has been identified using the steps described below.

5.3.1 Step 1: Estimate Energy Sales Revenues

Revenues for a medium-Btu gas project come from gas sales to a direct use customer. Potential landfill gas customers include industrial energy users, commercial buildings, universities, incinerators, and district heating systems. Typically, medium-Btu gas customers will buy landfill gas at a price that is no higher than their current delivered price of natural gas on a Btu basis, since landfill gas combustion may require burner retrofits, controls, and maintenance that natural gas does not. In fact, landfill gas project owner/developers should expect to offer landfill gas at a discount off the customer's current natural gas price; discounts of approximately ten to twenty percent are common in existing projects. Delivered natural gas prices vary by location and customer type. For example, the price paid by a large industrial gas user will likely be less than that of a customer who only uses gas for space heating purposes such as commercial buildings and district heating systems. Box 5.7 illustrates these price variations, which should be kept in mind when negotiating with potential customers.

**Box 5.1 Multiple End Uses of Landfill Gas Create a
Baseload Demand for
Fred Weber, Inc.**

Fred Weber, Inc., a cement and asphalt producer, collects landfill gas from a landfill near St. Louis, Missouri and directly uses the medium-Btu gas in three different, seasonal applications, for savings of about \$100,000 per year.

- In the summer months, landfill gas is burned in the aggregate dryer at the firm's asphalt plant which is located adjacent to the landfill.
- In the winter months, Fred Weber, Inc. uses landfill gas in its concrete plant to heat water for the preparation of ready-mixed concrete.
- Landfill gas is also used to heat the firm's adjacent commercial greenhouse.

By using landfill gas in complementary applications, Fred Weber, Inc. has created a baseload demand for its landfill gas supply.

[Mahin, 1991]

Box 5.1 Natural Gas Price Variations by Customer Type

Natural gas consumers can either purchase their own gas supplies and then pay the local distribution company (LDC) a delivery charge, or they can purchase delivered supplies directly from the LDC. Most large industrial and commercial consumers choose the former purchase alternative, since it is usually less expensive than buying from the LDC.

Regardless of the purchase strategy used, large industrial customers typically pay less for natural gas than other types of consumers:

<u>Residential</u>	<u>Industrial</u>	<u>Commercial</u>
Average Price (\$/mcf)	3.00	5.22
6.89		

All dollar values are in 1994 dollars.

[Energy Information Administration, 1995]

Displacement savings, realized by using landfill gas to offset natural gas purchases at facilities owned by the landfill owner/operator, should also be credited to the project.

Tax credits or other incentives may be used to supplement gas revenues. However, if the tax credits are to be used by a third party developer, they may not yield full face value to the project since there are soft costs (i.e., legal and transaction fees) associated with placing the ownership of the gas rights and collection system with an independent party. In addition, if the company cannot fully use the credits, the company may transfer the credits to an outside investor. These outside investors usually buy the credits at a discounted price, leaving the sellers with as little as 60% of the full value of the tax credit.

5.3.2 Step 2: Quantify Capital and O&M Costs

The gas collection costs for a medium-Btu gas sales project would be similar to those incurred in a power

project, although gas processing costs would probably be much less, since only minimal clean-up is usually required for direct use applications. The capital costs associated with delivering landfill gas to the customer would normally include pipeline construction costs (about \$250,000 to \$500,000 per mile, installed), additional gas compression costs, and metering. If there are low points in the pipeline which would allow moisture to accumulate, then the costs of installing dehydration equipment may also be incurred.

The customer may incur capital costs if equipment retrofits are necessary in order to burn landfill gas. For example, due to the lower flame temperature of landfill gas as compared to natural gas, lower boiler superheater temperatures may be experienced and thus a larger boiler superheater could be required [Eppich and Cosulich, 1993]. Retrofit costs will vary, since most require customized installation. For example, one project reported that new rotary kiln burners would cost \$30,000 each [LaReaux, 1995], while boiler burner retrofits may range in cost from \$120,000 to \$300,000 [Brown, 1995]. The landfill project may assume some of these retrofit costs, as was the case in the AT&T project described in Box 5.8.

Box 5.1 Medium-Btu Gas Sales to AT&T

Network Energy of Ohio, owner of landfill gas rights at a landfill near Columbus, Ohio, is selling landfill gas to a nearby AT&T Network Wireless Systems plant. The AT&T plant uses the landfill gas as boiler fuel to generate about 40,000 pounds of steam per hour for plant heating, process uses, and hot water heating. Use of the landfill gas enables AT&T to reduce the purchases of its normal boiler fuel--natural gas. Even with some natural gas still used to supplement the landfill gas supply, AT&T expects to achieve annual fuel savings of about \$100,000.

To make the medium-Btu purchase attractive to AT&T, Network Energy paid the \$1 million cost of building a 1.5-mile pipeline from the landfill to the plant and converting one AT&T boiler to burn landfill gas. A custom low-NOx burner was designed by Coen Company to burn a controlled mixture of landfill gas and natural gas. The burner control system is able to respond to changes in landfill gas line pressure and Btu content.

The agreement between Network Energy and AT&T provides that all key boiler equipment installed in the conversion is owned by AT&T. In addition, AT&T had input in the design process and obtained the air permit for the modified burner. Network Energy is responsible for ensuring that all other environmental conditions are met [Source: Power, April 1994].

Table 5-6

Table 5-1 Estimated Medium-BTU Project Capital Costs
at Example Landfill

shows the total capital costs for the example 5 million metric ton landfill, serving a gas consumer who is assumed to be located one mile away. The cost of providing gas to this customer is estimated to be \$3.39 million, including the cost of the gas collection system. These costs (in as-spent dollars, reflecting a June 1996 on-line date) would increase with longer pipeline distances.

O&M costs are relatively low for medium-Btu gas projects. The gas consumer is usually responsible for the O&M of its own fuel-burning equipment. For the project developer, gas delivery system O&M expenses might include pipeline marking costs (to prevent pipeline rupture during excavations), labor costs, insurance, and property taxes. The Wilder's Grove landfill gas project in North Carolina reports that its only routine gas delivery system maintenance tasks are to clean the automated condensate drain filter and replace the pumping station filter when significant pressure drops occur [Augenstein and Pacey, 1992].

Gas collection system O&M costs are calculated to be about \$0.31 per MMBtu in 1996 dollars [EPA, 1993].

5.3.3 Step 3: Compare Project Expenses and Revenues

To evaluate the economics of selling medium-Btu gas, the expenses associated with collecting, processing, and delivering the landfill gas must be compared against the gas revenues. A first-year comparison can give a quick estimate of project economic feasibility, while a pro forma model of cash flows will provide a more precise model of economic performance.

Using the capital cost assumptions described in Table 5-6, the first year cost of producing a medium-Btu fuel for direct use can be calculated for the example 5 million metric ton landfill. The results are presented in Table 5-7.

Table 5-1 Estimated Cost of Producing Medium-BTU
Gas at Example Landfill

Costs are displayed in the example for a baseload gas user, who consumes gas at a relatively constant rate over the course of a day or year, and a heat load user, who consumes gas mainly for seasonal heating needs. The results of the cost calculations affirm the following conclusions about medium-Btu gas projects in general:

- The incremental cost of installing a gas delivery system is very low. For the example landfill, the cost of the gas delivery system represents only about 23% of the total capital requirement.
- The fuel consumption pattern of a potential gas customer greatly affects the unit cost of gas. The example shows that producing and delivering gas to a heat load only customer would cost over twice that of producing and delivering to a baseload customer (\$2.87 per MMBtu versus \$1.28 per MMBtu on a total system basis).
- IRS Section 29 tax credits can make a substantial difference in offsetting gas production costs. When the full benefit of tax credits is factored into the cost of an incremental gas delivery system, the gas can essentially be recovered for free.

5.3.4 Steps 4 and 5: Create a Pro Forma and Assess Economic Feasibility

As with landfill gas power projects, the next steps in the project development process are to create a pro forma and assess economic feasibility. The concepts for analyzing a medium-Btu gas project are the same as those for a power project:

- Step 4: Create a pro forma that includes a listing of financial assumptions and operating parameters, energy pricing data, calculation of annual expenses and revenues, an income statement, a cash flow statement, and financial results.

Step 5: Assess economic feasibility based on cash flows, debt coverage ratios, owner's ROR, and NPV of cash flows.

5.4 ALTERNATIVE OPTIONS

Although the conventional power generation option and the medium-Btu gas sales option account for the vast majority of landfill gas energy recovery projects, there are several additional gas use alternatives that may be worth exploring. These alternatives, described briefly below, include: upgrading landfill gas to pipeline quality gas; using landfill gas as a vehicle fuel; using landfill gas in niche applications; and using landfill gas in fuel cells.

5.4.1 Upgrade to Pipeline Quality Gas

Upgrading gas to pipeline quality is relatively expensive, because of substantial processing requirements to remove nitrogen and other constituents of raw landfill gas. This option is currently viable only at larger landfills (i.e., more than 4 million cf per day) where significant economies of scale can be achieved. Landfill gas developers report that the revenues required to support such a project are in the range of \$3.62 to \$4.14 per MMBtu (1994\$) [SCS Engineers, 1994]. Tax credits, such as IRS Section 29 credits, may be available to qualifying projects to help the economics of this type of project. Higher natural gas prices would increase the attractiveness of this option.

Local distribution companies (LDCs) are the best potential market for upgraded gas sales, because they have a large existing market for the gas. The price an LDC will pay for upgraded landfill gas will probably be based on the price it pays for natural gas from producers and gas marketers. There are many different pricing methods used by LDCs. One of the most common is to index the gas price to the monthly market, or "spot," price. Spot prices vary among geographic areas and pipeline systems, and they fluctuate month-to-month. In the last few years, spot prices have been low due to a glut of natural gas supply on the market. Although this glut is disappearing, gas prices are not expected to increase dramatically in the next few years. LDCs may require gas testing for certain constituents, and assurances that these constituents will be removed or kept to a very low level.

5.4.2 Vehicle Fuel Applications

There are a few potential vehicle fuel applications for

landfill gas - compressed natural gas (CNG), liquified natural gas, and methanol - that are in the early stages of development or commercialization. At this time, CNG and other alternate-fuel vehicles make up a very small percentage of automobiles in the U.S., so there is not a large demand for CNG as a vehicle fuel. Environmental regulations may increase demand; for example, in southern California and the Northeast, alternate-fuel vehicles are expected to become a way to reduce local ozone pollution. Recent federal regulations may favor methanol produced from a renewable source, such as landfill gas.

Cost savings can be realized for landfill owner/operators who own vehicles or other nearby fleets (e.g., municipal vehicles, delivery trucks) that can be converted to run on alternate fuels. Key factors in the economic evaluation of this option are: (1) the cost of installing a fueling station; and, (2) the costs of retrofitting vehicles to run on the alternate fuel. The cost of installing a compressed landfill gas fueling facility can be significant--the installation of the Puente Hills Landfill fueling station in California cost approximately \$1 million [McCord, 1994]. However, under the Energy Policy Act of 1992, a federal tax deduction of up to \$100,000 is available for the installation of alternate fueling stations [Webb, 1992; Adkins, 1995]. Vehicle conversion costs, which currently run about \$3,500 for passenger vehicles and \$4,000 for trucks, can also be offset by tax deductions.⁸ Up to \$2,000 per vehicle is available for conversions of conventional fuel vehicles and up to \$5,000 per vehicle is available for medium-duty fleet purchases or conversions [GRI, 1995].

Fleet vehicles are an especially good application for alternate fuels because these vehicles usually travel less than 200 miles per day and they return to a central location at night for refueling and storage. Also, having a fleet of vehicles will increase fuel usage and therefore decrease average fuel costs, since capital recovery of fueling station construction costs represents the majority of fuel production costs (operation and maintenance costs for alternate fuel vehicle stations are minimal). For example, fuel costs at the Puente Hills CNG station range from 48¢ per gallon gasoline equivalent at a 100 percent station utilization factor to \$1.26 per gallon gasoline equivalent at a 25 percent station utilization factor [Wheless, Thalenburg, Wong, 1993].

5.4.3 Fuel Cells

⁸ Note that the tax deduction applies to the conversion of vehicles to various alternate fuels (e.g., CNG, LNG, LPG, or methanol).

The use of fuel cells to chemically convert landfill gas to electricity is a promising application, largely because of the high efficiency and minimal emissions resulting from this process. At this time, use of fuel cells for landfill gas applications is in the demonstration phase.

The phosphoric acid fuel cell (PAFC) is one of the three types of fuel cells suitable for stationary power production. This technology is considered commercially viable today, for other fuels, and there are over 40 MW of PAFC demonstration units in operation [Swanekamp, 1995]. The capital cost of the PAFC unit is \$3,000 per kW for delivery in 1995, and is projected to decrease to approximately \$1,500 per kW by 1998 [Strait, Doorn, and Roe]. Variable O&M costs for the units are estimated to be 1.7¢/kWh [FCCG, 1993].

Landfill gas-powered fuel cells are in the demonstration phase. Northeast Utilities installed a test unit at the Flanders Road Landfill in Groton, Connecticut in late 1995, and operation at the site began in June, 1996. Northeast Utilities expected to spend \$150,000 to install and maintain the 200 kW fuel cell. [Electric Power Daily, 1995]. Currently, Connecticut Light & Power, a subsidiary of Northeast Utilities, is operating and maintaining the test unit. The \$1.5 million, 200-kW PAFC demonstration unit, owned by the EPA, has already been tested at the Penrose Landfill in Sun Valley, CA.

5.4.4 Niche Applications

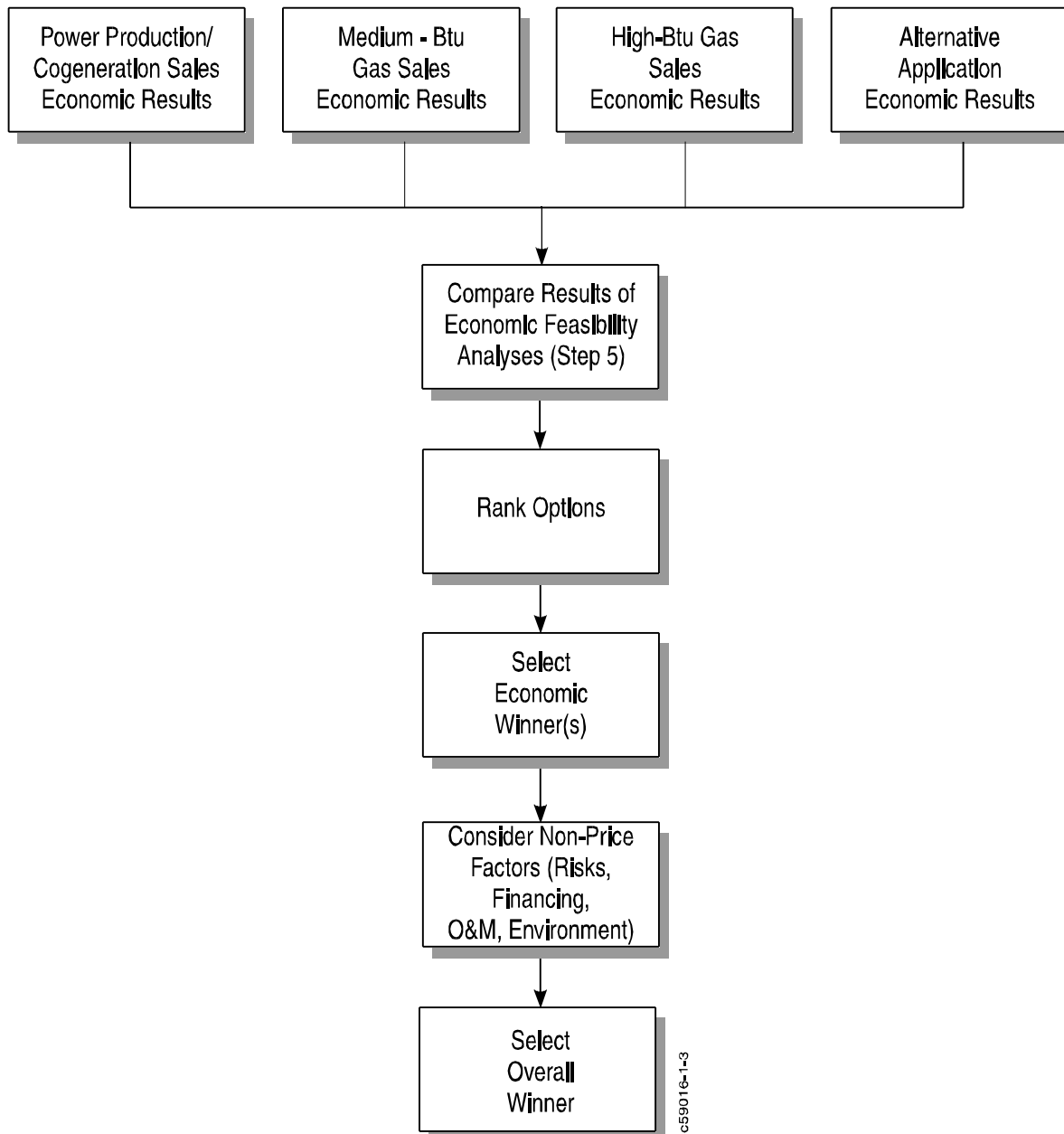
An important alternative application, particularly for smaller and/or closed landfills, is the local use of landfill gas for niche applications such as heating of greenhouses. Where these applications are available, they may be the most economically attractive for landfills that fail the economic tests of traditional applications. The costs of these applications will vary, depending on type of equipment used. For example, if landfill gas is used in an existing natural gas boiler to heat a greenhouse, costs may be minimal if burner adjustment is all that is required.

Other niche applications are currently being developed, such as the use of landfill gas to produce commercial high purity carbon dioxide (CO₂). With retail prices for this product between \$50 and \$200 per ton (1992\$), this may become a valuable use of landfill gas [Strait, Doorn, and Roe]. The process used to recover landfill gas CO₂ is in the field-scale testing and demonstration phase.

5.5 COMPARISON OF ALL ECONOMICALLY-FEASIBLE OPTIONS

If a landfill owner/operator has the opportunity to produce and sell more than one type of energy product, he or she should compare the net cash flows of each option head-to-head to determine the best option, as illustrated in Figure 5.2

Figure 5-1 Deciding Among Energy Project Options



. After completing an initial economic analysis for each option, including the development of a pro forma for the most promising options, the owner/operator can compare the results of the economic analysis (Step 5). After ranking the options and selecting an economic winner, the landfill owner/operator should then consider non-price factors including risks, ability to obtain financial backing, environmental performance, and reliability of assumptions. The option that produces the best financial performance while meeting the desired environmental, risk, and operating requirements is the winner.

5.5.1 Head-to-Head Economic Comparison

The results of Step 5 of the economic analysis--annual cash flows, NPV, debt coverage, and ROR--can be used independently or together to rank options and select an economic winner. There is no single measure of financial performance that guarantees economic viability, so it is wise to consider several measures together. One approach is to rank options according to the NPV of future after-tax cash flow, making sure that minimum debt coverage and ROR requirements are also met. The option with the highest NPV that meets the minimum debt coverage and rate of return requirements is the economic winner.

5.5.2 Consideration of Non-Price Factors

Although economic feasibility and financial results are important, the final selection of the project technology and configuration should take into account non-price factors such as environmental performance, reliability, and accuracy of assumptions. In the power generation example used above, the IC engine produced the maximum income for the owner, but the use of a CT may still be more attractive if low nitrogen oxide (NO_x) emissions are a priority (see Chapter 9). The permitting process might determine that low NO_x emission levels are required, potentially making the IC engine more expensive and/or more difficult to permit than the CT. As another example, a medium-Btu gas sale may show superior economic results when compared to the power generation options, but there may be additional risks entailed in pipeline construction or boiler conversion. Non-price factors have real impacts on project viability and must be taken into consideration.

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6. ASSESSING FINANCING OPTIONS

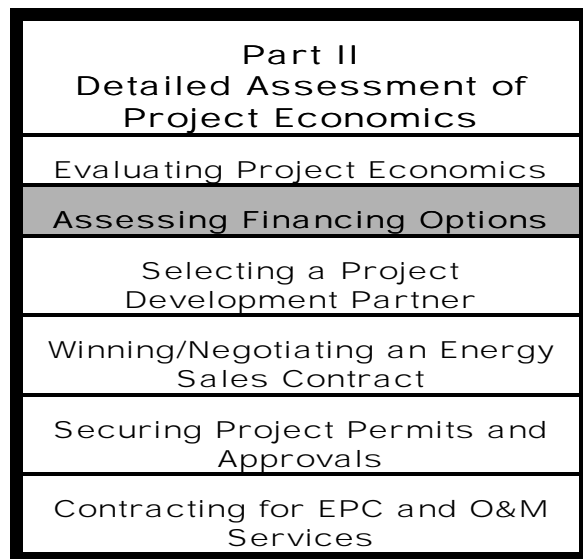
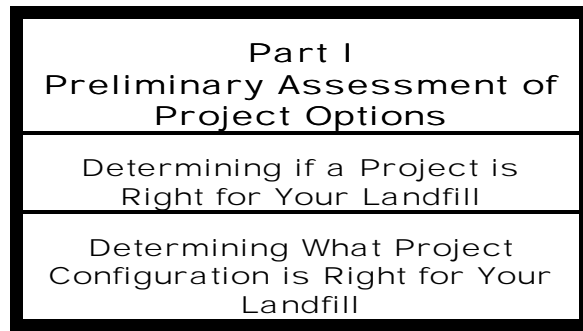
Financing a landfill gas energy recovery project is one of the most important and challenging tasks facing a landfill owner or project developer. A number of potential financing avenues are available, including finding equity investors, using project finance, and issuing municipal bonds. This chapter provides insights into what lenders and investors look for under each financing method, how to secure financing, and some advantages and disadvantages of each method.

The following six general categories of financing methods may be available to landfill gas projects:

- (1) private equity financing
- (2) private nonrecourse debt financing (i.e., "project financing")
- (3) municipal bond financing
- (4) direct municipal funding
- (5) lease financing
- (6) public financing through institutional or public stock offerings

The first four types are common among smaller energy projects such as landfill gas projects. Of the last two types, lease financing is used occasionally and public financing is not commonly used for landfill gas projects, but landfill owners should be aware that they exist. A recent survey of landfill gas energy projects concluded that private debt or equity financing was used in 85% of the cases [Berenyi and Gould, 1994]. The same survey showed that over 10% of

The Project Development Process



the projects were funded directly by city, county, or other municipal revenues.

The selection of financing method is usually driven by cost and applicability, since not all financing methods are available to all types of projects and project owners. A flow chart that illustrates the general process of deciding on the optimal financing method is presented in Figure 6.1.

Figure 6-1: Assessing Financing Options

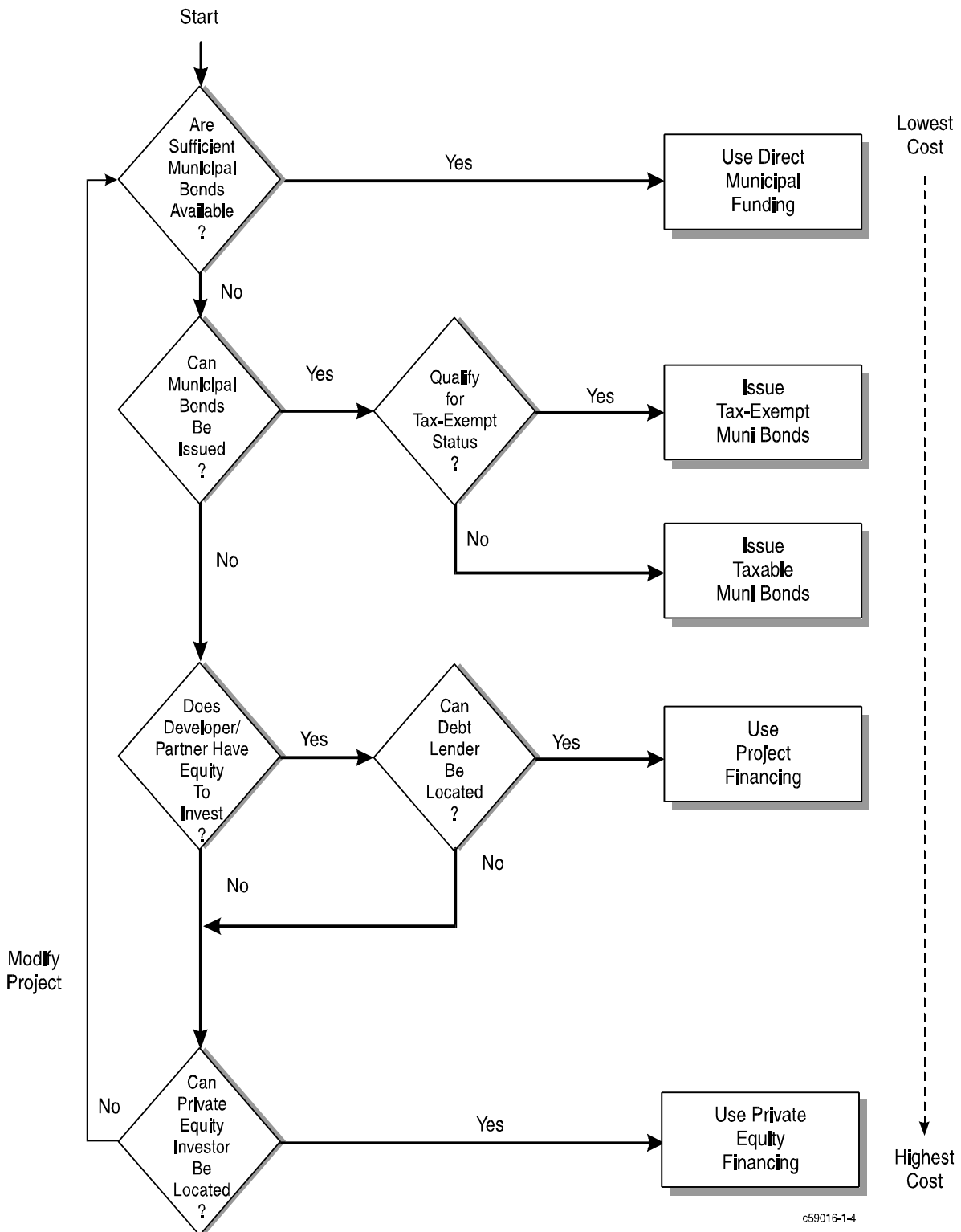
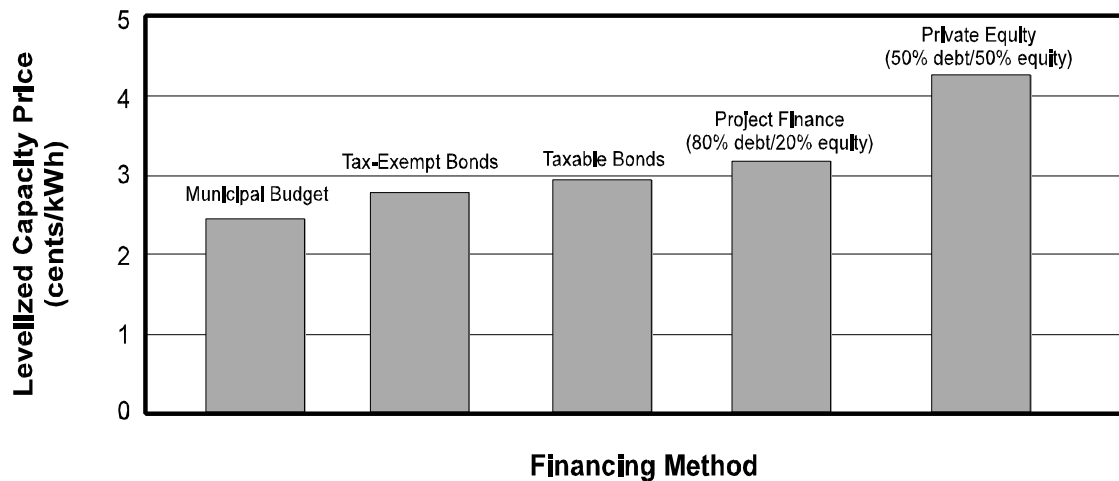


Figure 6-1: Capacity Price Produced by Different Financing Approaches

5 Million metric ton landfill example IC engine electric generating project



The cost effects of various financing methods are illustrated in Figure 6.2, which shows a sample capacity price for the same project under different financing methods. The capacity price incorporates the cost of building and financing a landfill gas project, annualized over the project life. It is sensitive to interest rates; higher interest rates lead to higher financing costs and a more expensive project compared with a lower interest rate scenario.

From the landfill owner's perspective, often the simplest and lowest cost financing method is to use direct municipal funding through the municipal operating budget. Because

the amount of municipal funds available is usually limited, however, this method may not be possible for many projects. Issuing municipal bonds is also a low-cost option, particularly for projects owned by a public agency, but local and federal applicability rules must be satisfied in order to use this method. If neither of these options is viable, then the project must look to higher-cost debt or private equity for financing. Selecting a developer with equity to invest or a demonstrated ability to obtain financing for landfill gas projects is a convenient strategy for landfill owners exploring these financing options.

6.1 FINANCING: WHAT LENDERS/INVESTORS LOOK FOR

Most lenders and investors decide whether or not to lend to or invest in a landfill gas project based on the expected financial performance of the project. Financial performance is usually evaluated using a pro forma model of project cash flows (discussed in Chapter 5). Thus, preparing a detailed pro forma is an important step in ensuring the financial feasibility of a landfill gas energy project.

A lender seeking demonstration of project financial strength will usually examine the following measures:

- Debt coverage ratio - The lender's main measure of project financial strength is the ability of a project to adequately meet debt payments. Debt coverage ratio is the ratio of operating income to debt service requirement and is usually calculated on an annual basis. Debt coverage ratios are usually expected to be in the 1.3 to 1.5 range.
- Owner's rate of return (ROR) on equity - The desired ROR currently ranges from about 12% to 18% for most types of power projects. Outside equity investors will typically expect a ROR of 15% to 20% or more, depending mainly on the project risk profile. These RORs reflect early-stage investment situations; investments that are made later in the development or operation phases of the project typically receive lower returns because the risks have been substantially reduced.

The feasibility of a particular landfill gas energy project is also determined by the quality of supporting project contracts and permits, and by risk allocation among project participants. The uncertainties about whether a power project will perform as expected or whether assumptions

will match reality are viewed as risks. To the extent possible, the project's costs, revenues, and risk allocation are spelled out through contracts with energy purchasers, equipment suppliers, fuel/landfill gas suppliers, engineering/construction firms, and operating firms, as well as through the presence of permits, developer experience, and financial commitments. Table 6-1

Table 6-1 Addressing Landfill Gas Energy Project Risks

Risk Category	Risk Mitigation Measure
Landfill gas availability	<ul style="list-style-type: none"> • Drill test wells, monitor samples • Hire expert to report on gas availability • Model gas production over time • Execute gas delivery contract/penalties with landfill owner • Provide for back-up fuel if necessary
Construction	<ul style="list-style-type: none"> • Execute fixed-price turnkey contracts • Include monetary penalties for missing schedule • Establish project acceptance standards, warranties
Equipment performance	<ul style="list-style-type: none"> • Select proven technology • Design for landfill gas Btu content • Design to take landfill gas impurities into account • Get performance guarantees, warranties from vendor • Include major equipment vendor as partner • Select qualified operator
Environmental permitting	<ul style="list-style-type: none"> • Obtain permits prior to financing (air, water, building) • Plan for condensate disposal
Community acceptance	<ul style="list-style-type: none"> • Purchase site, sign lease, execute option agreement • Obtain zoning approvals • Demonstrate community support
Power sales agreement (PSA)	<ul style="list-style-type: none"> • Have signed PSA with local utility, or industrial plant • Match PSA pricing, escalation to project expenses • Where possible, get capacity payment to cover fixed costs • Get sufficient term to match debt repayment schedule • Confirm interconnection point, access, requirements • Make sure online date is achievable • Include force majeure provisions in PSA

summarizes the principal project risk categories, viewed from the beginning of the development process, and presents possible risk mitigation strategies, the most important of which are usually obtaining contract(s) securing project revenues and verification of landfill gas availability. Potential lenders and investors will look to see how the project developer has addressed each risk through contracts, permitting actions, project structure, or financial strategies.

6.2 FINANCING APPROACHES

Capital for landfill gas energy projects is most commonly obtained from private equity financing, project financing, municipal bonds, or direct municipal funds. This section focuses on the lenders' requirements, the means of securing financing, and the advantages and disadvantages of each of the four major financing approaches. Two other potential financing methods - lease financing and public debt financing - are also discussed briefly.

6.2.1 Private Equity Financing

Historically, private equity financing has been one of the most widely used methods of financing landfill gas energy projects. In order to use private equity financing, an investor must be located who is willing to take an ownership position in the landfill gas energy project. In return for a significant share of project ownership, the investor is willing to fund part or all of the project costs using its own equity or privately placed equity or debt. Some landfill gas developers are potential equity investor/partners, as are some equipment vendors, fuel suppliers, and industrial companies. Investment banks are also potential investors. The advantages and disadvantages of private equity

**Box 6-1 Private Equity Financing --
Advantages/Disadvantages**

Advantages

- For some power projects under 20 MW without access to municipal bonds, this may be the only means of obtaining financing.
- Transaction costs are usually less than with project financing or bond financing.
- Equity partners can often move faster than commercial lending institutions, enabling tight project schedules to be met.
- Bringing in an equity or subordinated debt partner is an effective means of risk-sharing, provided that the risk allocation is reflected in the project structure.

Disadvantages

- Equity is expensive; returns on equity will be paid to the investor out of project cash flows.
- Project owners will have to give up some project ownership and control to an equity investor.
- The addition of a subordinated debt partner can complicate the financing process if project financing is being used.
- A partner who is an equipment vendor, fuel company, or industrial company might have different objectives than the landfill owner (e.g., operation for optimum emissions control may not be a priority).

financing are presented in Box 6.1. The primary advantage of this method is its availability to most projects; the primary disadvantage is its high cost.

Equity investors typically provide equity or subordinated debt for projects. Equity is invested capital that creates ownership in the project, like a down-payment in a home mortgage. Equity is more expensive than debt, because the equity investor accepts more risk than the debt lender. (Debt lenders usually require that they be paid before

project earnings get distributed to equity investors.) Thus the cost of financing with equity is usually significantly higher than financing with debt. Subordinated debt gets repaid after any senior debt lenders are paid and before equity investors are paid. Subordinated debt is sometimes viewed as an equity-equivalent by senior lenders, especially if provided by a credit-worthy equipment vendor or industrial company partner.

Investor's Requirements

The equity investor will conduct a thorough due diligence analysis to assess the likely ROR associated with the project. This analysis is similar in scope to banks' analyses, but is often accomplished in much less time because of the entrepreneurial nature of equity investors as compared to institutional lenders. The equity investor's due diligence analysis will typically include a review of contracts, project participants, equity commitments, permitting status, technology and market factors. The key requirement for most pure equity investors is sufficient ROR on their investment. The due diligence analysis, combined with the cost and operating data for the project, will enable the investor to calculate the project's financial performance (e.g., cash flows, ROR) and determine its investment offer based on anticipated returns. An equity investor may be willing to finance up to 100% of the project's installed cost, often with the expectation that additional equity or debt investors will be located later.

Some types of partners that might provide equity or subordinated debt may have unique requirements. Potential partners such as equipment vendors, fuel suppliers, and industrial companies generally expect to realize some benefit other than just cash flow. The desired benefits may include equipment sales, service contracts, tax benefits, and economical and reliable energy supplies. For example, an engine vendor may provide equity or subordinated debt up to the value of the engine equipment, with the expectation of selling out its interest after the project is built. A fuel supplier might also become an equity partner to gain access to a low-cost gas supply, or a nearby industrial company might want to gain access to fuel or derived energy. The requirements imposed by each of these potential investors are sure to include not only an analysis of the technical and financial viability, but also a consideration of the unique objectives of each investor.

Securing Private Equity Financing

To fully explore the possibilities for private equity or subordinated debt financing, landfill owners should ask potential developers if this is a service they can provide. The second most common source of private equity financing is an investment bank that specializes in the private placement of equity and/or debt. Additionally, the equipment vendors, fuel companies, and industrial companies that are involved in the project may also be willing to provide financing for the project, at least through the construction phase. The ability to provide financing is often an important

consideration when selecting a developer, equipment vendors, and/or other partners.

6.2.2 Project Finance

"Project finance" is a method for obtaining commercial debt financing for the construction of a facility, where lenders look at the credit-worthiness of the facility to ensure debt repayment rather than at the assets of the developer/sponsor. In most project finance cases, lenders will provide project debt for up to about 80% of the facility's installed cost and accept a debt repayment schedule over 8 to 15 years. Project finance usually provides the option of either a fixed rate loan or a floating rate loan, which is tied to an accepted interest rate index (e.g., U.S. treasury bills, London Interbank rate). Typically, the facility sponsor(s) will set up a separate subsidiary company to develop and manage the facility, and lenders in effect provide financing to the subsidiary company with limited or no recourse to the subsidiary's parent(s). Thus project financing is often known as "nonrecourse" financing because the project debt is secured by facility assets and contracts, with no recourse (or limited recourse) to parent companies should the facility experience financial under-performance or failure.

Most private power projects, especially those built in the last 15 years by third-party developers, were completed using project finance. The major advantages and disadvantages of project finance are listed in Box 6.2. The biggest advantage of project finance is the ability to use others' funds for financing, without giving up ownership control. The biggest disadvantages are the difficulty of obtaining project finance for landfill gas projects, which tend to be smaller than traditional power projects. In addition, project finance transactions are costly and often an onerous

process of satisfying lenders' criteria.

**Box 6-1 Project Finance -
Advantages/Disadvantages**
Advantages

- Project debt is usually nonrecourse to the landfill owner and/or energy project sponsor; however, the owner and sponsor remain liable for explicit warranties and misrepresentations.
- The project debt can usually be kept off the project sponsor's balance sheet.
- Project sponsors can retain sole or majority ownership of the landfill energy project.

Disadvantages

- The small capital requirements of landfill gas projects relative to other power projects can make project financing difficult to obtain, because transaction costs and risk perceptions remain high.
- Lenders usually require most key contracts and permits to be in place on or before financial closing, which adds to project lead time.
- Lenders may place other requirements on the project such as minimum equity contribution, minimum debt coverage, and creation of a major maintenance fund.
- Debt must usually be repaid over an 8 to 15 year term.

Lenders' Requirements

In deciding whether or not to provide project finance to a power project, lenders examine not only the expected financial performance of the project; they also consider several other factors that underlie facility success such as contracts, project participants, equity stake, permits, technology, and sometimes market factors. A good candidate for project financing should have most, if not all, of the following:

- Signed energy sales agreement from a credit-worthy electricity or gas customer (e.g., utility, industrial, municipality)
- Fixed-price agreement with engineering/construction firm(s)
- Equity commitment
- Operation and maintenance agreement
- Fuel supply analysis and supply/transport agreement(s)
- Control of the project site (e.g., option agreement or ownership)
- Environmental permits
- Local permits/approval

In addition, lenders may place additional requirements on the project developers such as maintaining a certain minimum debt coverage ratio and making regular contributions to an equipment maintenance account, which will be used to fund major equipment overhauls.

In addition, in cases where project finance is used, lenders generally expect the project sponsors to make some equity commitment of their own. An equity commitment shows that project sponsors also have a financial stake in project success, and it implies that sponsors will be more likely to step in with additional funds if problems arise. The expected debt-equity ratio is usually a function of project risks. In the mid-1980s, some power projects obtained project financing with little or no equity contribution, based mainly on the financial strength of the project and supporting contracts. However, most lenders now do not accept such highly leveraged projects and instead require at least a 20% equity stake on the part of project sponsor(s).

Securing Project Financing

Landfill gas projects have historically experienced some difficulty securing project financing, because of their relatively small size and the perceived risks associated with the technology. In addition, the transaction costs for arranging project financing are relatively high, owing to the lender's extensive due diligence (i.e., financial and risk investigation) requirements; it is often said that the transaction costs may be the same for a 10 MW project as for a 100 MW project. For this reason, most of the project finance groups at the large commercial banks and investment houses hesitate to lend to projects with capital requirements less than about \$20 million (or a 20 MW or larger power project).

The best opportunities for landfill gas projects to secure project financing are generally with the project finance groups at smaller investment capital companies and banks, or at one of several energy investment funds that commonly finance smaller projects. Some of these lenders have experience with landfill gas projects and may also be attuned to the unique needs of smaller projects. Depending on the project economics, some investment capital companies and energy funds may consider becoming an equity partner in the landfill gas project in addition to, or instead of, providing debt financing. Additionally, it is worth contacting local and regional commercial banks. Some of these banks have a history of providing debt financing for small energy projects, and may be willing to provide project financing to a "bundle" of two or more landfill gas projects.

6.2.3 Municipal Bond Financing

Municipally owned landfills occasionally issue tax-preferred municipal bonds to finance landfill gas energy projects. The biggest benefit of using this financing method is that the resulting debt has an interest rate that is often 1% to 2% below commercial debt or taxable bond debt (see Box 6.3). For a bond issue to qualify for tax-exempt status, a number of complex IRS conditions concerning project ownership and purpose must be met. Additionally, state-specific laws and policies may also impact the ability to issue tax-exempt bonds. Since the rules governing the applicability of tax-exempt bond financing are complex, it is wise to consult the IRS tax code and a tax expert before

deciding on a particular approach.

**Box 6-1 Municipal Bond Financing -
Advantages/Disadvantages**
Advantages

- Tax exempt financing provides access to debt at interest rates that are 1% to 2% below the rates offered by commercial lenders.
- Debt repayment can be extended over the life of the facility, which may be 20 years or more.

Disadvantages

- The financial performance requirements (e.g., debt coverage, cash reserves) placed on the project by the bond issuer may exceed project finance lender's requirements.
- Public disclosure requirements exist.
- The project may have to contend with state caps on the amount of private activity bonds that can be issued.
- It is difficult to obtain additional capital for the project in cases where the design, equipment, or other conditions change.

The important factors in qualifying for and obtaining municipal bond financing are described below.

Lenders' Requirements

Generally speaking, a government entity (e.g., municipality, public utility district, county government) can issue either tax-exempt governmental bonds or private activity bonds, which can be either taxable or tax-exempt. Bonds can either be secured by general government revenues (i.e., revenue bonds), or by the specific revenues from the energy project (i.e., project bonds). The term for bond financing usually does not exceed the useful life of the facility; terms extending up to 30 years are not uncommon, however.

In addition to initial qualification requirements, many tax-exempt bond issuers find that strict debt coverage and cash reserve requirements must be imposed on an energy project to ensure that the financial stability of the issuer is preserved. These requirements may be even more rigorous than those imposed by commercial banks under a project finance approach.

Securing Municipal Bond Financing

To qualify for a governmental bond issue, a project must meet at least two criteria:

- (1) Private business use test - No more than 10% of the bond proceeds are to be used in the business of an entity other than a state or local government.
- (2) Private security of payment test - No more than 10% of the payment of principal or interest on the bonds can be directly or indirectly secured by property used for private business use.

Under these rules, a government entity could issue tax-exempt governmental bonds to finance a landfill gas energy project if the project would be owned and operated by the same government entity. If private owners or operators are involved, however, the project may not qualify for tax-exempt governmental bond status [Snohomish, 1994; Martin, 1993]. Private business use can include private ownership of all or part of a landfill gas project.

If a particular project fails to qualify for a governmental bond issue, it may still achieve tax-exempt bond status through one of several exemptions for projects that provide some form of public benefit. Among these exemptions are at least two that could apply to certain landfill gas projects with partial private ownership [Kulakowski, 1994; Martin, 1993]:

Local furnishing of electricity - Tax-exempt status is provided for a power project that sells electricity to a utility (public or investor-owned) that is a net importer of power and serves no more than two contiguous counties or one county and one contiguous city. It is unclear whether or not the financing for the landfill gas extraction/collection portion of the project can be included in this exemption.

Local district heating and cooling - Tax-exempt status is provided for an energy project that sells steam, chilled water, and/or other thermal energy to two or more

unrelated entities, which must be within two counties. The exemption covers the equipment used to generate the thermal energy.

Two additional exemptions may be applicable to landfill gas projects, although it is unknown whether any landfill gas projects have successfully used these exemptions:

Prepayment of fuel supply - Tax-exempt status is provided for a governmental entity that purchases a long-term fuel supply such as gas reserves. Tax-exempt status covers only the purchase of fuel supplies that are used in electric generation which serves a governmental entity.

Solid waste disposal - Tax-exempt status is provided for facilities that burn solid waste fuel that has no market value as a saleable product.

The mechanics of issuing municipal bonds vary according to the type of bond, method of qualification, and the state or municipality in which the bond is issued. Qualified local tax or financial experts should be consulted for guidance.

6.2.4 Direct Municipal Funding

Landfill gas energy recovery projects can also be funded directly through the operating budget of a city, county, landfill authority, or other municipal government. Using this method, the costs of project development, equipment, and installation are expensed directly from the municipal budget, thus eliminating the need for outside financing or partnering. Typically this method is used to fund small projects that fit within the municipality's budget capabilities and priorities. Advantages and disadvantages

are described in Box 6.4.

**Box 6-1 Direct Municipal Funding -
Advantages/Disadvantages**
Advantages

- The need to meet tough lender's requirements (e.g., debt coverage, equity input, credit-worthiness, contracts in place) is eliminated, although any municipal funding criteria must still be met.
- Expensing the project's funding requirements directly from the municipal budget will eliminate interest charges on project debt, making this generally the lowest-cost financing method.
- The project is not subject to delays caused by lenders' time requirements for evaluating the project and setting up the financing.

Disadvantages

- Usually the amount of municipal funds are limited, thus limiting the size of the project.
- The municipality loses the opportunity to share risks with other project partners.
- A public approval process may be required, making the project vulnerable to political forces.

6.2.5 Lease Financing

Lease financing encompasses several leasing strategies in which the project operator/equipment user leases part or all of the energy project assets from the asset owner(s). Typically, lease arrangements provide the advantage of enabling the transfer of tax benefits such as accelerated depreciation or energy tax credits to an entity that can best use them. Lease arrangements commonly provide the lessee with the option, at predetermined time intervals, to purchase the assets or extend the lease. Several large equipment vendors have subsidiaries that lease equipment, as do some financing companies. There are several variations on the lease concept including:

Leveraged Lease - In a leveraged lease, the equipment user leases the equipment from the owner, who finances the equipment purchase with external debt and possibly equity.

Sale-Leaseback - In a sale-leaseback, the equipment user buys the equipment, then sells it to a corporation, which then leases it back to the user under contract.

Some of the disadvantages of lease financing include accounting and liability complexities, as well as the loss of tax benefits by the project operator/user.

6.2.6 Public Debt Financing

Financing power projects with public debt such as secured notes and bonds offered to institutional investors has recently received much attention from developers of large, conventional-fueled power projects. This approach is not likely to be an option for the typical landfill gas project, however, unless several high-quality landfill gas projects can be "packaged" together under single ownership. In this case, the debt could be raised for the package of projects through a single offering, and due diligence costs would be minimized by standardizing the projects. In order to qualify for public debt financing, a project must be rated at or near investment grade by rating agencies, have solid supporting contracts, and be large enough - approximately \$100 million or more - to offset the transaction costs.

6.3 CAPITAL COST EFFECTS OF FINANCING ALTERNATIVES

Each financing method produces a different weighted cost of capital, which affects the amount of money that is spent to pay for a landfill gas power project and the price that is needed to cover project costs. The weighted cost of capital is dependent on the share of project funds financed with debt and equity, and on the cost of that debt or equity (i.e., interest rate on debt, ROR on equity). For example, in a project finance scenario with a debt/equity ratio of 80/20, an interest rate on debt of 9%, and an expected ROR on equity of 15%, the weighted cost of capital is 10.2%. Decreasing the amount of debt to 70% means that more of the project funds must be financed with equity, which carries a higher interest rate than debt, so the weighted cost of capital becomes 10.8%. Increasing the weighted cost of capital means that project revenues must be increased to pay the added financing charges. In contrast a lower weighted cost of capital lessens the amount of money

spent on financing charges, which makes the project more competitive.

Among the four main financing methods presented above, direct municipal funding usually produces the lowest financing costs over time, while private equity financing produces the highest. Generally speaking, the four financing methods are ranked from lowest cost to highest cost as follows:

- 1) Direct municipal funding
- 2) Municipal bond financing
- 3) Project financing
- 4) Private equity financing

The advantage associated with direct municipal funding is created by the elimination of interest on debt, and by the low expected ROR. Municipal bond financing achieves its advantage through access to low-interest debt - assumed to be currently about 6.5% for tax-exempt bonds and 8.25% for taxable bonds [Snohomish, 1994]. Project finance produces a higher capacity price because funds are required to pay interest charges as well as ROR on equity (assumed to be 15%). Finally, private equity is the most expensive because it usually demands a higher ROR (assumed to be 18%) on equity than project finance, and equity makes up a larger share of the capital requirement.

Interest rates are an important determinant of project cost if the project sponsor decides to borrow funds, either through lending institutions or bond offerings, to finance the project. For example, raising interest rates by 1% would cause an increase of about 2% to 3% in the cost of generating electricity from a landfill gas project. Interest rates are determined by the prevailing rate indicators at a particular time, as well as by the project and lender's risk profiles. The interest rate for fixed-rate nonrecourse debt is usually determined by the lender's "spread" over an index such as U.S. treasuries. Likewise, the interest rate for floating-rate nonrecourse debt is based on a spread above variable indices such as the prime rate or the London Interbank Offered Rate (LIBOR). The lender's spread varies widely, but a landfill gas project with reliable gas availability, experienced participants, and a strong power purchase contract might expect a spread of 2.0% to 2.75% above the index. [Seifullin, 1995; DePrinzio, 1995]. Smaller projects requiring less than roughly \$5 million of nonrecourse debt could also expect to pay an interest rate premium to compensate the lender for disproportionate transaction costs.

Table 6-2 Capital Cost Effects of Financing Approaches

added, as described in Chapter 5, to determine the total project cost. The more common private equity structure is

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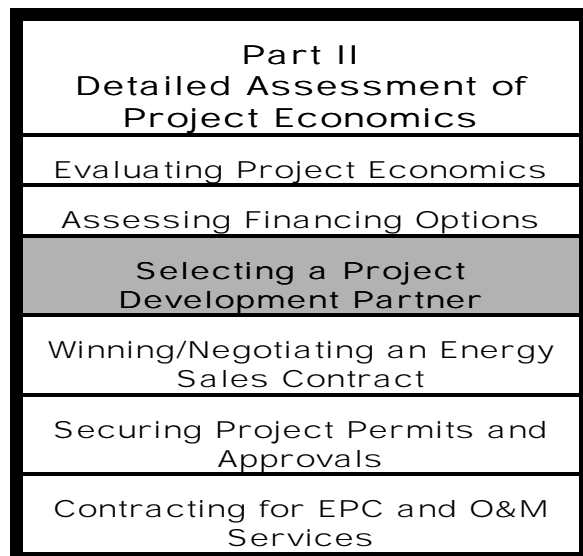
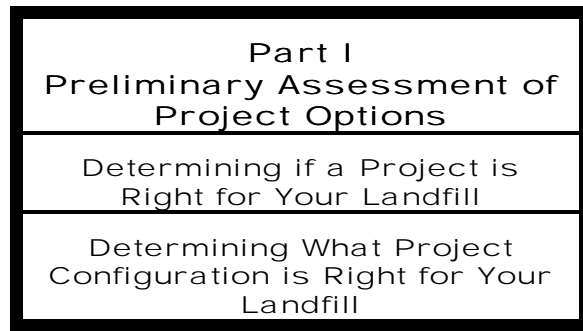
7. SELECTING A PROJECT DEVELOPMENT PARTNER

The selection of a project development partner is a critical decision because the landfill owner often relies on the developer to manage the process of transforming a landfill energy project from a feasible idea on paper into a functioning, multi-million dollar facility. Some landfill owners have the expertise, resources, and desire to lead the development effort on their own, but even in this case, choosing the right development partner(s) can greatly improve the likelihood of project success. This chapter provides guidance to landfill owners who are attempting to determine: (1) the role that they might take in the development process; and (2) the right partner to get the project developed, financed, and built.

From the landfill owner's perspective, there are three general ways to structure the development and ownership of a landfill gas energy project:

- (1) Develop the project internally - Landfill owner manages the development effort and maintains ownership control of the project. This approach maximizes economic returns to the owner, but also places most of the project risks on the owner (e.g., construction, equipment performance, financial performance).
- (2) Team with a pure project developer - Landfill owner selects a qualified developer to develop and build the project. This option shifts most risks onto the developer, but the landfill owner usually gives up control, ownership rights, and some or all of the

The Project Development Process



potential for financial returns. A variation on this option is selecting a developer to provide the landfill owner with a "turnkey" plant, which is built by the developer but owned by the landfill owner.

- (3) Team with a partner - Landfill owner teams with an equipment vendor, engineering/procurement/construction (EPC) firm, industrial company, or fuel company to develop the project and to share the risks and financial returns.

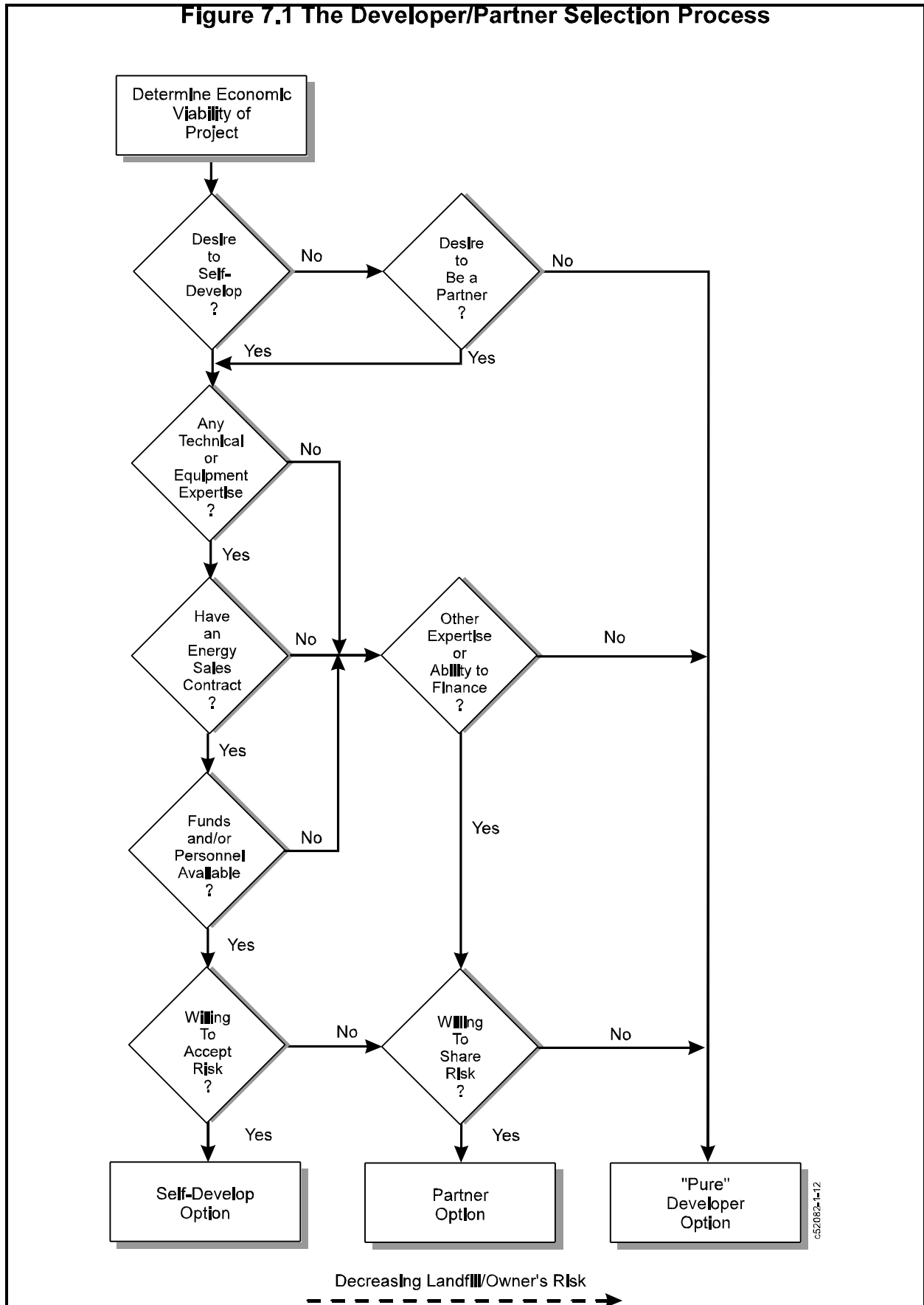
With these structures in mind, a landfill owner can determine his or her desired role in the project development process by considering two key questions:

- Should the landfill owner self-develop or find a partner?
- If a partner is desired, what kind of partner best complements the landfill owner and the project?

The landfill owner can answer the first question by conducting a frank examination of his or her own expertise, objectives, and resources. The second question is more complicated because it entails an assessment of the landfill owner's specific needs and a search for the right partner to complement those needs.

Figure 7.1

Figure 7.1 The Developer/Partner Selection Process



illustrates the process of determining the best development approach. As it indicates, in cases where the landfill owner wants to be involved in the project development process, a number of issues must be considered. These issues are discussed in the following sections.

7.1 THE PARTNER/NO PARTNER DECISION

Before deciding whether to develop the project internally, the landfill owner must understand the role of the project developer, which is outlined in Box 7.1.

Box 7.1 The Role of the Project Developer

Determine Landfill Gas Supply - If the landfill owner has not already completed this step, then the first development step will be to determine the landfill gas supply using calculations, computer modeling, and/or test wells.

Scope Out the Project - Project scoping includes early-stage tasks such as selecting a location for the equipment, sizing the energy output to the landfill gas supply, contacting potential energy customers, and selecting key equipment.

Conduct Feasibility Analysis - Feasibility analysis includes detailed technical and economic calculations to demonstrate the technical feasibility of the project and estimate project revenues and costs.

Select Equipment - Based on the results of the feasibility analysis, primary equipment is selected and vendors are contacted to assess price, performance, schedule, and guarantees.

Create a Financial Pro Forma - A financial pro forma is usually created to model the cash flows of a project and to predict financial performance.

Prepare the Bid - If the project must bid in a utility solicitation in order to obtain a power sales agreement (PSA), a responsive bid package will be prepared and submitted.

Negotiate the Power Sales Agreement (PSA) - The terms of the PSA must be negotiated with the purchasing electric utility.

Negotiate the Gas or Steam Sales Agreements - For projects that intend to sell landfill gas or steam, agreements must be negotiated with the energy customers.

Obtain Environmental and Site Permits - All required environmental permits and site permits/licenses must be acquired.

Gain Regulatory Approval - Some power projects must obtain approval from state regulators or certification by

Next, an assessment of the landfill owner's objectives, expertise, and resources will determine whether or not the owner should undertake project development independently or include a partner/developer. A landfill owner who is a good candidate for developing a project alone will have many of the following attributes:

- strong desire to develop a successful, profitable energy project;
- willingness to accept project risks (e.g., construction, equipment, permitting, financial performance);
- expertise with technical projects (e.g., power, infrastructure, or industrial) or energy equipment;
- high confidence level regarding landfill gas quantity and quality (i.e., modeling or test wells have been completed);
- possession of a power sales agreement with a local electric utility, an electric consumer, a gas purchaser, or sufficient internal demand; and
- funds and personnel available to commit to the development process.

In addition, other attributes may improve a landfill owner's likelihood of success in developing a project in-house. Ownership or control of multiple landfills, for example, may be desirable because it will enable the owner to leverage his/her time and resources spent. Similarly, a strong desire for new business opportunities and/or visibility may be beneficial. An example of the type of landfill owner that fits this profile is a municipal utility district that might have responsibility for local electricity procurement and distribution, water supply, and/or sewage treatment, in addition to landfill management.

If the landfill owner is uncertain about several of the attributes listed above, particularly the desire to develop, the willingness to take significant risks, and/or their level of technical

expertise, then he or she might instead choose a partner. The following are several good reasons to develop the project with a partner:

- limited desire to lead the development effort;
- limited technical resources and/or experience;
- need to share or avoid specific project risks;
- difficulty financing the project alone;
- inability to dedicate personnel or time to the development effort;
- project development outside the scope of organizational charter; and
- difficulty spending funds to determine landfill gas quantity.

The questions in Figure 7.1 illustrate other critical considerations in making the partner/no partner decision.

Most landfill owners choose to bring in a developer to build and/or own the energy recovery project, either alone or in partnership with the landfill owner or others. A recent survey of existing and planned landfill gas energy recovery projects shows that about 78% of gas collection systems and 88% of gas processing/energy recovery systems are owned by private firms or in partnership with private firms [Berenyi and Gould, 1994].

7.2 SELECTING A DEVELOPMENT PARTNER

Once the decision has been made to include a project development partner, the next step is to decide what type of partner to select. There are several different types of development partners to choose from, so the landfill owner should look for a partner that provides the best match for the specific energy project and the landfill owner's in-house capabilities. Five general types of project development partners, listed in order of decreasing scope of services, include:

Pure Developer - A firm primarily in the business of developing, owning, and/or operating landfill gas energy projects. Some developers focus on landfill gas power projects, while others may be involved in a broad project portfolio of technologies and fuel types. Pure

developers usually will own the completed landfill gas energy facility, but sometimes a developer will build a turnkey facility for the landfill owner.

Equipment Vendor - A firm primarily in the business of selling power or energy equipment, although it will participate in project development and/or ownership in specific situations where its equipment is being used. The primary objective of this type of developer is to help facilitate purchases of its equipment and services.

EPC Firm - A firm primarily engaged in providing engineering, procurement, and construction services. Some EPC firms have project development groups that develop energy projects and/or take an ownership position.

Fuel Company - A firm primarily engaged in providing fuels and/or fuel procurement services. These firms may have project development subsidiaries or agree to take a specific development role such as securing a customer for the landfill gas.

Industrial Company - A firm primarily engaged in manufacturing a product and managing an industrial manufacturing facility. Some industrial firms have power project development subsidiaries or may take a specific role such as guaranteeing energy purchases or assisting with financing.

Ideally, a developer or partner can be identified that fills specific project needs such as ability to secure a power purchase contract, finance the project, or supply equipment. Issuing a request for proposals (RFP) is often a good way to attract and evaluate partners.

A partner reduces risks to the landfill owner by bearing or sharing the responsibilities of project development, although the amount of risk reduction provided depends on the type of partner chosen. For example, a "pure developer" partner will usually take the risk/responsibility of construction, equipment performance, environmental permitting, community acceptance, energy sales agreements, and financing, whereas an equipment vendor partner may only bear the risks of equipment performance.

7.2.1 Selecting a Pure Developer

Selecting a pure project developer to manage the development process and own the landfill gas energy project is a good way for the landfill owner to shed

development responsibility and risks, and get the project built at no net cost to the landfill. In addition, the pure project developer typically provides the landfill owner with the strongest development skills and experience, since pure developers focus exclusively on landfill gas projects. Other reasons for selecting a pure project developer include:

- the developer's skills and experience may be invaluable in bringing a successful project online;
- some developers are ready to invest equity or have access to financing; and
- the developer might be in possession of a power sales agreement that was previously won and/or negotiated with a nearby electric utility.

In return for accepting project risks, most developers require a significant share of project profits, potentially up to 100 percent. As a result, the landfill owner generally loses control and ownership of the energy project. Such an ownership arrangement may be appropriate for a particular landfill if, for example, development of an energy recovery system is the lowest cost method for complying with environmental regulations. It may also be necessary to involve a developer in order to take advantage of IRS Section 29 tax credits (see Chapter 5 for more on tax credits). If the developer becomes the sole or controlling owner, however, he/she will tend to make decisions to protect his/her interest in the project, namely the energy revenues, and may be less concerned with the landfill owner's priorities such as controlling landfill gas migration.

The case of the I-95 Landfill in Lorton, Virginia illustrates the key issues involved in taking the pure developer approach. As described in Box 7.2,

this landfill partnered with a pure developer to develop a successful energy recovery project. By carefully structuring its contract with the developer, the landfill owner was able to ensure that safety and other concerns were given top priority by the developer.

Box 7.1 Developer Selection at I-95 Landfill

The I-95 Landfill Project in Lorton, Virginia illustrates one landfill owner's successful experience in selecting a project developer. The I-95 Landfill Project is a 17.5 million ton sanitary landfill that supports a 6,400-kw electric generating system, using 8 Caterpillar internal combustion engines. The landfill gas collection system is owned and operated by Fairfax County and the electric generating equipment is owned by Landfill Energy Systems, a division of Michigan Cogeneration Systems.

Fairfax County found that selecting a pure developer resulted in the successful completion of the landfill gas power project. Fairfax County hired a consultant to assess the landfill gas quantity and quality, then issued a request for proposals (RFP) to select a project developer. The developer ultimately selected to build the project had experience with other landfill gas projects, a power sales agreement with the local utility, and the ability to finance the project.

A thoughtful contracting approach eliminated potential conflicts between the developer and landfill owner. Fairfax County was most concerned with controlling landfill gas migration and emissions, while the developer wanted to optimize gas output for power generation. The two parties recognized that the best gas collection strategy for minimizing gas migration is often different from the strategy that maximizes power output. In a worst case scenario where an uncooperative developer owns the gas collection system, a landfill owner might be forced to drill collection wells at the landfill perimeter to control offsite migration, which could draw gas away from the developer's collection wells. To avoid this potential scenario, Fairfax County opted to keep control of the entire collection system and now supplies landfill gas to Landfill Energy Systems' electric generating equipment.

Arranging for a turnkey project represents a variation on the pure developer approach. The turnkey option is a good approach if the landfill owner wants to retain energy project ownership or the project's return on investment does not meet the developer's criterion. In a turnkey approach, the developer assumes development responsibility and construction risk, finances and builds the facility, and then transfers ownership to the landfill owner when the facility is complete and performing up to specifications. In return, the developer can receive a fee, a share of project proceeds, gas rights, and/or a long-term operation and maintenance contract. Sometimes the landfill owner will use municipal bonds to finance the project, so the developer essentially develops and builds the project for a fee. The turnkey approach enables each entity to contribute what it does best: the developer accepts development, construction, and performance risk; and the owner accepts financial performance risk.

7.2.2 Selecting a Partner (Equipment Vendor, EPC Firm, Fuel Firm, Industrial)

Selecting a development partner who is not a pure developer is a good choice if two key conditions exist:

- (1) The landfill owner wants to keep management control of the project and has sufficient in-house expertise and resources to do so; and,
- (2) The partner can fulfill a specific role or provide equipment for the project.

In this case, the landfill owner must have a clear desire to manage the development process and should have sufficient technical experience, personnel, and development funds to support the development effort. The owner should also have a relatively high confidence level regarding landfill gas production capability, as well as a willingness to accept a significant share of the project's risks (e.g., financial, environmental permitting, community acceptance). Other factors that could make the partnering approach an appropriate choice include the ownership of a power or energy purchase agreement, or control of multiple landfills that could each be developed into a landfill gas project, thus leveraging the time and resources invested.

There are four basic types of firms that enter into partnership agreements with landfill operators: equipment vendors, EPC firms, fuel suppliers, and industrial companies. Each of these firms have different strengths and will assume different types of project risk. The key

characteristics of these types of firms are summarized below.

Equipment vendors: Some equipment vendors such as engine and turbine manufacturers become partners in energy projects, including landfill gas projects, as a way to support the sale of equipment and services to potential customers. Equipment vendors may assist in financing the project, and are often willing to accept the equipment performance risk over a specified length of time for the equipment that they provide. However, equipment vendors typically do not take on responsibilities beyond their equipment services, and they generally want to sell their interest in a project as quickly as possible after the project has been built.

EPC firms: Similarly, some of the larger EPC firms will become partners in power projects with the objective of selling services and gaining a return on equity and/or time invested. However, this type of potential partner tends primarily to pursue large fossil-fueled projects where the EPC's strength as a manager of large, complex projects is more valuable.

Fuel suppliers: A fuel supplier or marketing company can be a potential development partner in landfill gas projects where marketable gas is the energy product for sale. For example, a local natural gas distribution company might become a partner to gain access to a local, low cost gas supply. This type of partner would typically take a very limited role such as guaranteeing a market for the landfill gas or owning the gas collection and processing systems. However, several natural gas suppliers and pipeline companies also have power project development subsidiaries that resemble pure developers in terms of experience and capabilities, and that may be willing to take on a larger role in the project.

Industrial companies: Finally, an industrial company might become a partner in the landfill gas project if it has significant use for the landfill gas or derived energy (i.e., electricity, steam). The industrial company is likely to prefer a limited involvement in the development process.

7.3 EVALUATING INDIVIDUAL FIRMS

Once the right partnering strategy has been identified, the landfill owner should review the capabilities of individual

firms that meet the owner's general needs. When selecting a firm to become a development partner, there are several qualities and capabilities that landfill owners should look for, including:

- previous landfill gas project experience;
- a successful energy project track record;
- access to capital and/or financing; and
- in-house resources (e.g., engineering, finance, operation) including experience with environmental permitting and community issues.

Information about individual firm qualifications can be gained from annual reports, brochures, and project descriptions, as well as from discussions with references, other landfill owners, and engineers. Potential warning signs include lawsuits, disputes with landfill owners, and failed projects, although a few failed development efforts and/or underperforming projects can normally be found in the portfolio of any project developer. Published information can be obtained by researching trade literature, through legal information services, and through computer research services.

7.3.1 Issuing a Request for Proposals (RFP)

A landfill owner may find it advantageous to issue an RFP for a developer or partner, because if the RFP is prepared correctly, respondents will generally offer creative, informative, and useful responses. The RFP process is a good way to screen proposals and focus on the best one(s) for further discussions and negotiation.

A landfill owner who plans on issuing an RFP should carefully examine his needs and ask respondents to propose ways to meet those needs or solve problems. For example, if a landfill gas energy project needs a power sales agreement or energy sales contract, then the landfill owner should state in the RFP that the ability to secure one of these agreements is a central selection criterion. Likewise, if ability to secure financing or environmental permits is important, that should also be stated in the RFP. In this way, respondents will be encouraged to offer innovative proposals that meet the project's specific needs.

In general, RFP respondents should be asked to provide the following information:

- Description of the energy project and available options;
- Scope of services being offered (e.g., developer, owner, operator);
- Project development history and performance;
- Pricing and escalation (e.g., royalties/payments to landfill owner, electricity price, energy prices) including buyout price and terms;
- Turnkey facility bid (if appropriate);
- Plan for obtaining energy revenues (e.g., PSA with utility, gas sales contract, steam contract);
- Technology description and performance data;
- Well placement strategy (if applicable);
- Well field operations responsibility;
- Responsibility for environmental compliance;
- Environmental permitting and community approval plan;
- Financing plan;
- Schedule; and
- Operation and Maintenance plan.

Landfill owners should state in the RFP that the owner reserves the right to select none, one, or several respondents for further negotiation, depending on the proposal's responsiveness to the owner's criteria. Appendix D contains a sample RFP that was issued by one landfill. This particular RFP is not very detailed; therefore, the respondent would have some leeway in preparing his or her bid package.

7.3.2 Preparing a Contract

Once the partner has been selected, the terms of the partnership should be formalized in a contract. The contract should accomplish several objectives, including allocating risk among project participants. Some of the key elements of a partnership contract are listed in Box 7.3.

As Box 7.3 indicates, contracting with a developer or partner in a landfill gas energy project is a complex issue. Each contract will be different depending on the specific nature of the project and the objectives and limitations of the participants. Because of this complexity, it is imperative that the landfill owner consult in-house counsel or hire a qualified attorney to serve as a guide through the contracting process.

Box 7.1 Elements of a Partnership Contract

The contract between the landfill owner and the developer or partner should describe in detail the responsibilities of each party, any payments to be made, and any warranties and/or guarantees. Some specific items that should be addressed include:

- Ownership shares;
- Allocation of development responsibility;
- Decisionmaking rights;
- Commitments of equity, financing, equipment, and/or services;
- Payments, fees, royalties;
- Hierarchy of project cash distributions;
- Allocation of tax credits;
- Allocation of specific risks (e.g., equipment performance, gas flow);
- Penalties, damages, bonuses;
- Schedule and milestones;
- Termination rights clause;
- Buy-out price; and
- Remedies/arbitration procedures.

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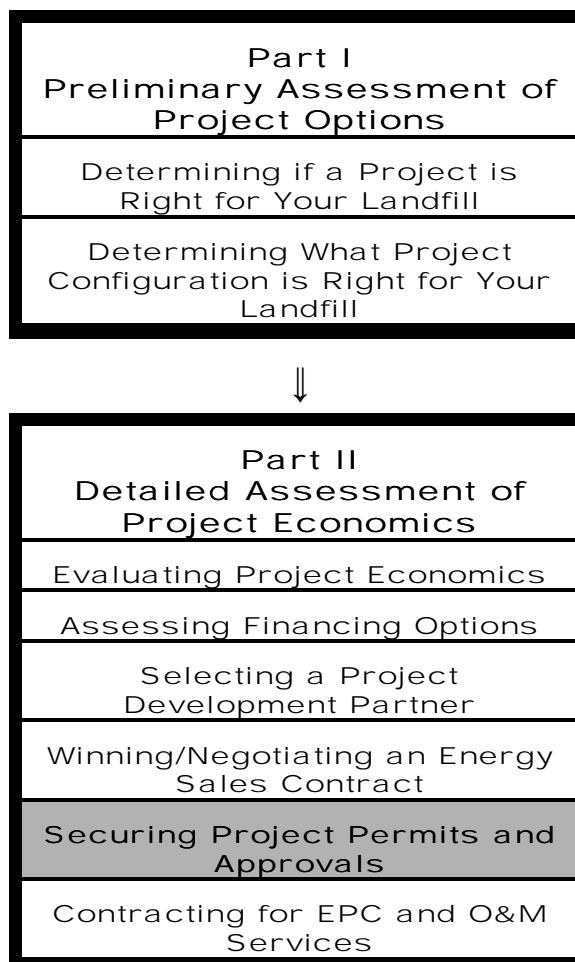
9. SECURING PROJECT PERMITS AND APPROVALS

Obtaining required environmental, siting, and other permits is an essential step in the development process. Permit conditions often affect project design, and neither construction nor operation can begin until all permits are in place. The process of permitting a landfill gas-to-energy project may take anywhere from six to eighteen months (or longer) to complete, depending on the project's location and recovery technology. For example, a project sited in a location that requires no zoning variances and that meets national air quality standards will probably take much less time to permit than a project subject to zoning hearings and stringent air quality requirements.

Landfill gas energy recovery projects must comply with federal regulations related to both the control of landfill gas emissions and the control of air emissions from the energy conversion equipment. Regulations promulgated under two separate federal acts specifically address emissions from municipal solid waste landfills:

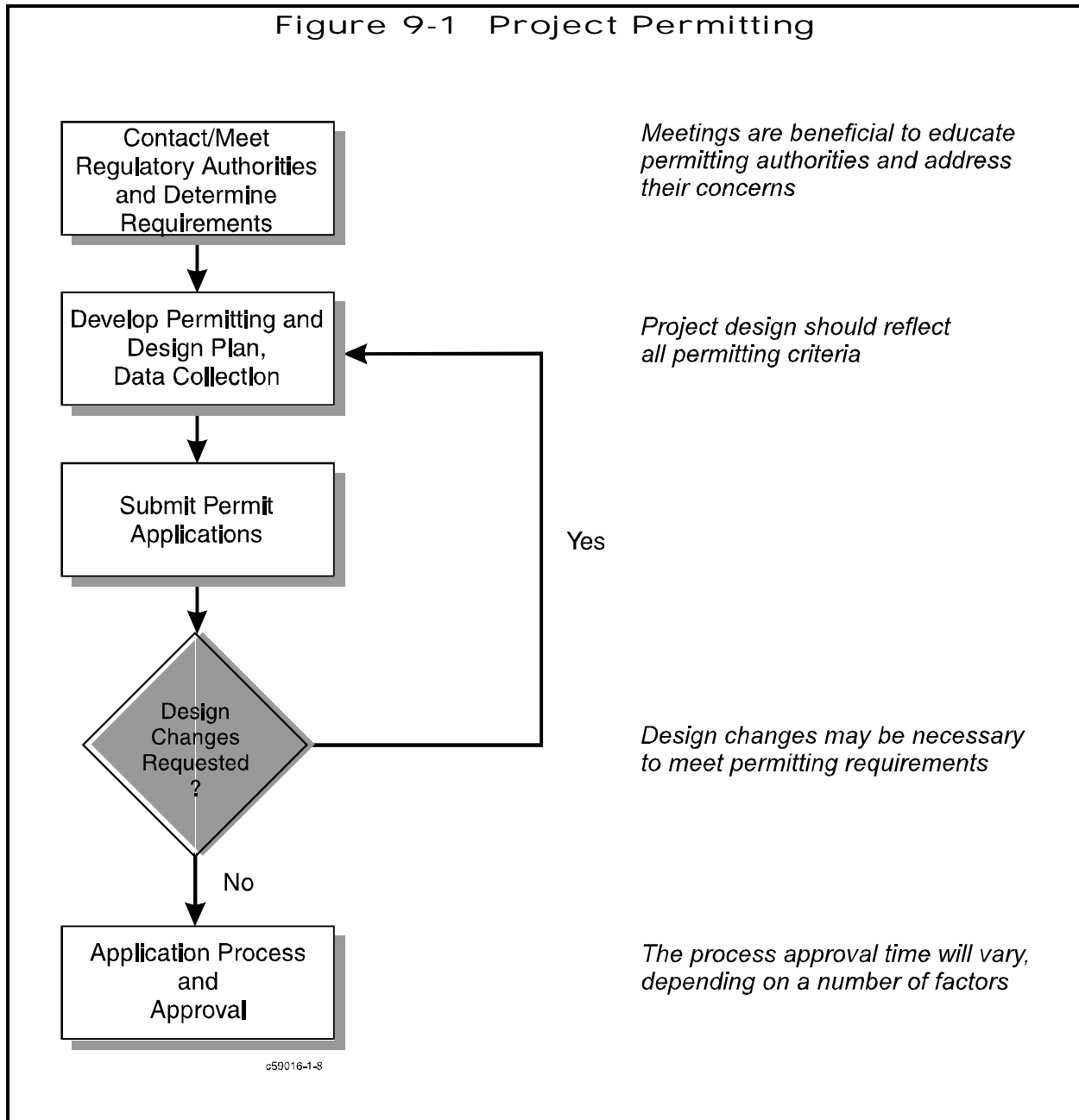
- Resource Conservation and Recovery Act (RCRA) regulations focus on landfill gas hazard and nuisance abatement [40 CFR, §258.23].
- Clean Air Act regulations focus on control of landfill gas emissions [61 FR 9905, March 12, 1996].

The Project Development Process



Air emissions from energy recovery projects are addressed in other sections of the Clean Air Act. This chapter briefly discusses these major federal regulations and their impacts on landfill gas energy recovery projects. It should be noted that states are generally granted the authority to implement, monitor, and enforce the federal regulations by establishing their own permit programs. As a result, some state permit program requirements are more stringent than those outlined in the federal regulations and there is a large state-to-state variance in agencies and standards. For this reason, landfill owner/operators and project developers should determine state and local requirements before seeking project permits.

Figure 9-1 Project Permitting



9.1 THE PERMITTING PROCESS

There are four general steps (outlined in the flowchart in Figure 9.1) that will help ensure that the necessary permitting requirements under applicable state and federal regulations are met:

Step 1. Hold preliminary meetings with key regulatory agencies. Discuss with regulators the requirements and issues they feel must be addressed. These meetings also give the developer the opportunity to educate regulators

about the project, since, in many cases, landfill gas-to-energy technologies may be unfamiliar to regulators.

Step 2. Develop the permitting and design plan. Determine the requirements and assess agency concerns early on, so permit applications can be designed to address those concerns and delays will be minimized.

Step 3. Submit timely permit applications to regulators. Submit complete applications as early as possible to minimize delays.

Step 4. Negotiate design changes with regulators in order to meet requirements. Permitting processes sometimes provide opportunities for project sponsors to negotiate the appropriate control measure and level with regulators. If negotiation is allowed, it may take into account technical as well as economic considerations.

As these steps indicate, the success of the permitting process relies upon a coordinated effort between the developer of the project and various local, state, and federal agencies who must review project plans and analyze their impacts. For landfill gas projects in particular, developers often must deal with separate agencies with overlapping jurisdictions over landfill operations and energy recovery operations (e.g., solid waste and air quality authorities). This underscores the importance of coordinating efforts to minimize difficulties and delays.

In some cases, permitting authorities may be unfamiliar with the characteristics and unique properties of landfill gas. Where appropriate, the landfill owner/operator or project developer should approach the permitting process as an opportunity to educate the permitting authorities, and should provide useful, targeted information very early in the process.

Emphasizing the pollution control aspects of landfill gas energy recovery projects can be an effective approach in seeking permits. If a landfill gas collection and flare system has not yet been installed or does not collect the full quantity of landfill gas emitted, then there is a substantial opportunity to reduce non-methane organic compounds (NMOC) and methane emissions from the landfill. An energy recovery project can further reduce these emissions by capturing additional landfill gas, as well as reducing emissions of carbon dioxide, sulfur dioxide, and other pollutants by

displacing a fossil fuel source. Approaching and presenting the project as a pollution control project that will cause a net reduction in emissions can make the air permitting process much easier.

9.2 RCRA SUBTITLE D

RCRA Subtitle D, established to ensure the protection of human health and the environment, sets minimum national design, operating and closure criteria for municipal solid waste landfills that were active on or after October 9, 1993. Virtually all currently operating municipal solid waste landfills are considered affected landfills under RCRA. Landfill gas control is one item addressed in the regulations.¹

Landfill gas control is achieved by requiring affected landfills to establish a program to periodically check for methane emissions and prevent offsite migration. Landfill owners or operators must ensure that the concentration of methane gas does not exceed: (1) 25 percent of the lower explosive limit for methane in facility structures (excluding gas control or recovery system components); and, (2) the lower explosive limit for methane at the facility boundary. Permitted limits on methane levels reflect the fact that methane is explosive within the range of 5 to 15 percent concentration in air. If methane emissions exceed permit limits, corrective action (i.e., installation of a landfill gas collection system) must be taken [40 CFR, §258.23]. Subtitle D may provide an impetus for some landfills to install energy recovery projects in cases where a gas collection system is required for compliance.

Subtitle D requirements for methane emissions monitoring affect landfills not only during operation, but also for a period of thirty years after closure.

9.3 CLEAN AIR ACT

The Clean Air Act (CAA) addresses landfill gas-to-energy recovery project emissions in two ways:

- (1) Regulation to control the emissions of non-methane organic compounds found in landfill gas, and
- (2) Regulation of airborne emissions from the combustion sources used in landfill gas energy recovery.

This section explains how the CAA regulations apply to and impact landfill gas energy recovery projects.

¹ RCRA Subtitle D applies to affected landfills, regardless of whether an energy recovery project is in place.

9.3.1 Landfill Gas Emissions

On March 12, 1996, EPA promulgated New Source Performance Standards (NSPS) and Emissions Guidelines (EG) for landfills under the authority of Title I of the Clean Air Act (61 FR 49, 9905, March 12, 1996). The regulations target landfill gas emissions because they contain non-methane organic compounds (NMOCs), which contribute to smog formation. The requirements of the NSPS and EG are basically the same, with the main difference being the timing of implementation and the lead agency--the EPA administers the NSPS which takes effect immediately, while the states implement the EG once they have completed and received EPA approval of their implementation plans.

The regulations require landfill gas control at municipal solid waste landfills that meet all of the following criteria:

Age - The NSPS apply to all "new" landfills--i.e., those that began construction, reconstruction, or accepting wastes for the first time on or after May 30, 1991 (the date the proposed regulations were published in the Federal Register). The EG apply to "existing" landfills--i.e., those that accepted wastes on or after November 8, 1987. Both "new" and "existing" landfills are referred to below as "affected" landfills." Landfills that were closed prior to that date are not subject to the regulations.

Capacity - Affected landfills with a design capacity greater than 2,500,000 Mg (2,750,000 tons) are subject to the emission rate criterion described below.

Emission rate - Affected landfills meeting the capacity criterion must collect and combust their landfill gas if their maximum annual NMOC emission rate is greater than 50 metric tons. This emission rate can be determined either by desktop calculation using an EPA model (known as a Tier One analysis), or by EPA-defined physical testing procedures (known as Tier Two or Tier Three determinations).

Affected landfills that must collect and combust their landfill gas can use a flare system or an energy recovery system that has been demonstrated to reduce NMOC emissions by 98 percent. Landfill gas-to-energy should be evaluated at each landfill site to determine whether it is cost-effective, as it offers landfill owners an opportunity to mitigate the costs of compliance with the regulations. In

addition to control requirements, the proposed regulations also contain recordkeeping and reporting requirements.

As the permitting process outlined in Figure 9.1 indicates, it will be important to contact regulatory authorities in order to determine and verify applicability criteria before developing a compliance plan. Appendix B is a list of regional and federal EPA offices that can provide detailed information about the regulations.

9.3.2 Regulations Governing Air Emissions from Energy Recovery Systems

Regulations have been promulgated under the CAA governing airborne emissions from new and existing sources. These regulations require new stationary sources and modifications to existing sources of certain air emissions to undergo the New Source Review (NSR) permitting process before they can operate.² The purpose of these regulations is to ensure that sources meet the applicable air quality standards for the area in which they are located. The applicable air quality standards are determined, in part, by the National Ambient Air Quality Standards (NAAQS), which have been set by EPA for six criteria air pollutants.

Two aspects of the NAAQS affect the stringency of the NSR permitting process. First, it sets overall regional ambient air loadings for the criteria pollutants. Using these levels, most areas of the country are classified as in "attainment" or "nonattainment" for each criteria pollutant. Areas that meet the NAAQS for a particular air pollutant are classified as in "attainment" for that pollutant, while areas that do not meet the NAAQS for a particular air pollutant are classified as in "nonattainment" for that pollutant. The same area may be in attainment for one air pollutant, but in nonattainment for another pollutant. Nonattainment areas are further categorized by their degree of nonattainment: marginal, moderate, serious, severe, and extreme. The greater the degree of nonattainment, the more stringent the regulations are in bringing that area to attainment and the lower the acceptable emission levels of particular pollutants will be. Some areas of the country are "unclassified" for all or some pollutants. An area that is listed as "unclassified" for a particular pollutant is one that has not had a project undergo the air permitting process for that pollutant.

²The EPA's NSR regulations for nonattainment areas are set forth in 40 CFR 51.165, 52.24 and part 51, Appendix S. The PSD program is set forth in 40 CFR 52.21 and 51.166.

Second, the NAAQS sets emission levels for new stationary sources and for modifications to existing sources. These levels are expressed in terms of total atmospheric loadings (i.e. tons emitted per year), as opposed to emission rates (tons/kwh), and are dependent upon location (attainment or nonattainment area) and the type of source (new or existing and its quantity of emissions). New sources or modifications to existing sources that exceed these NAAQS emission levels are classified as "major" sources while those that do not are classified as "minor" sources.

The principal air permitting requirements for landfill projects in attainment and nonattainment areas are described in detail below. As the discussion indicates, new stationary sources and modifications to existing sources in attainment areas undergo Prevention of Significant Deterioration (PSD) permitting while those in nonattainment areas undergo Nonattainment Area permitting. The basic difference between these processes is that the NSR permitting requirements are more stringent for major sources or modifications in nonattainment areas than for those same sources or modifications in attainment areas.

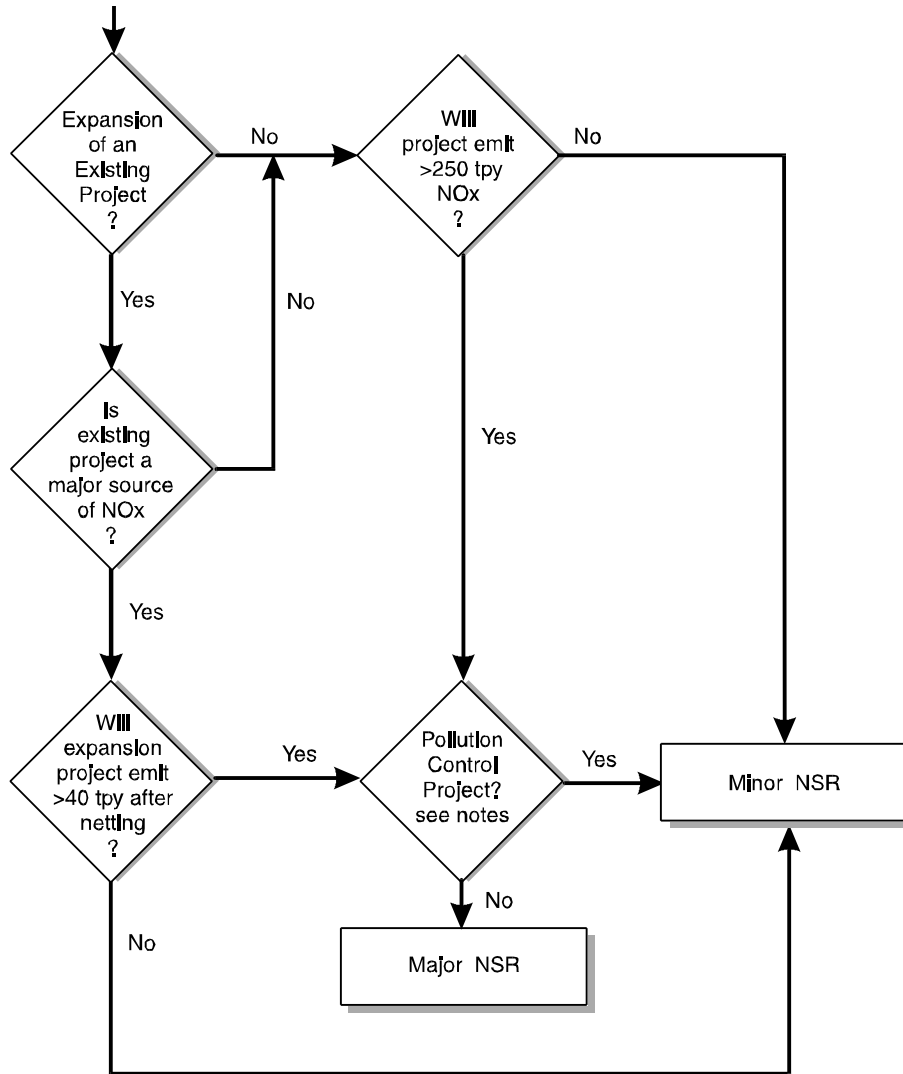
Most landfill energy recovery projects will likely be affected by the NAAQS standards for nitrogen oxides (NO_x) and carbon monoxide (CO). Whether a major NSR is required at a particular landfill project will depend on the level of emissions resulting from the project (which is primarily a function of project size and technology) and the project's location (attainment or one of the five degrees of nonattainment). As discussed below, small projects and/or those located in attainment areas may find the air permitting process to be quite straightforward (minor NSR), while larger projects, particularly those in nonattainment areas, may require major NSR, which is more extensive. In any event, given the complexity of the air permitting regulations, a landfill owner or operator may wish to consult a local attorney or other expert familiar with NSR permitting requirements in a particular area.

Attainment Area Permitting or PSD Permitting

PSD review is used in attainment areas to determine whether or not a new or modified emissions source will cause significant deterioration of local air quality. All areas are governed to some extent by PSD regulations because it is unlikely that a given location will be in nonattainment for all criteria pollutants. Applicants must determine PSD applicability for each individual pollutant. For gas-fired sources, including landfill gas energy recovery projects,

PSD and major NSR is required if the new source will emit or has the potential to emit any criteria pollutant at a level greater than 250 tons per year. A modification to an existing emission source is considered major if one of the following conditions is met: (1) the existing source is already a major source of a particular air pollutant and the modification will emit that air pollutant at a level greater than the PSD significance level or, (2) if the existing source is minor for a particular air pollutant and the modification will emit that air pollutant at a level greater than the major new source threshold. Figure 9.2

**Figure 9-1 Applicability of New Source Review Requirements
in Attainment Areas for Ozone:
Emissions of NO_x Used as an Example**



Notes:

A Pollution Control Project must be both:

- (a) environmentally beneficial; and
- (b) not cause or contribute to a violation of a NAAQS or PSD increment, or adversely affect an AQRV in a Class I area.

In addition:

- The permitting authority must determine that the project qualifies as a pollution control project.
- The permitting authority must provide an opportunity for public review and comment on the project's application and the proposed NSR exclusion.

shows a simplified flow diagram of determining whether a new source or modification is major in an attainment area.

For each pollutant for which the source is considered major, the PSD major NSR permitting process requires that the applicants determine the maximum degree of reduction achievable through the application of available control technologies. Specifically, major sources may have to undergo any or all of the following four PSD steps: (1) Best Available Control Technology (BACT) analysis, (2) monitoring of local air quality, (3) source impact analysis/modeling (i.e. impact on local air quality), and (4) additional impact analysis/modeling (i.e. impact on vegetation, visibility, and Class I areas). The key component of the PSD process is the BACT analysis, which requires that the most stringent

control technology available must be used in a facility, unless the applicant can demonstrate that it is not feasible due to energy, environmental, or economic reasons.

Minor sources and modifications are exempt from this rigorous process, but these sources must still obtain construction and operating air permits. Minor sources must demonstrate, through calculations, modeling, vendor guarantees, or other analysis, that the source's emissions will not exceed applicable PSD levels. Many states require even minor sources to complete a BACT analysis and use BACT, although minor sources are usually not required to gather local air quality data or model impacts. New sources or modifications are considered major for NO_x or CO if they exceed the limits shown in Table 9.1.

Table 9-1 Attainment Area Limits for NO_x and CO

Pollutant	New Sources are Considered Major if Emissions Exceed (in TPY)	Modifications to an Existing Minor Source are Considered Major if Emissions Exceed	Modifications to an Existing Major Source are Considered Major if Emissions Exceed

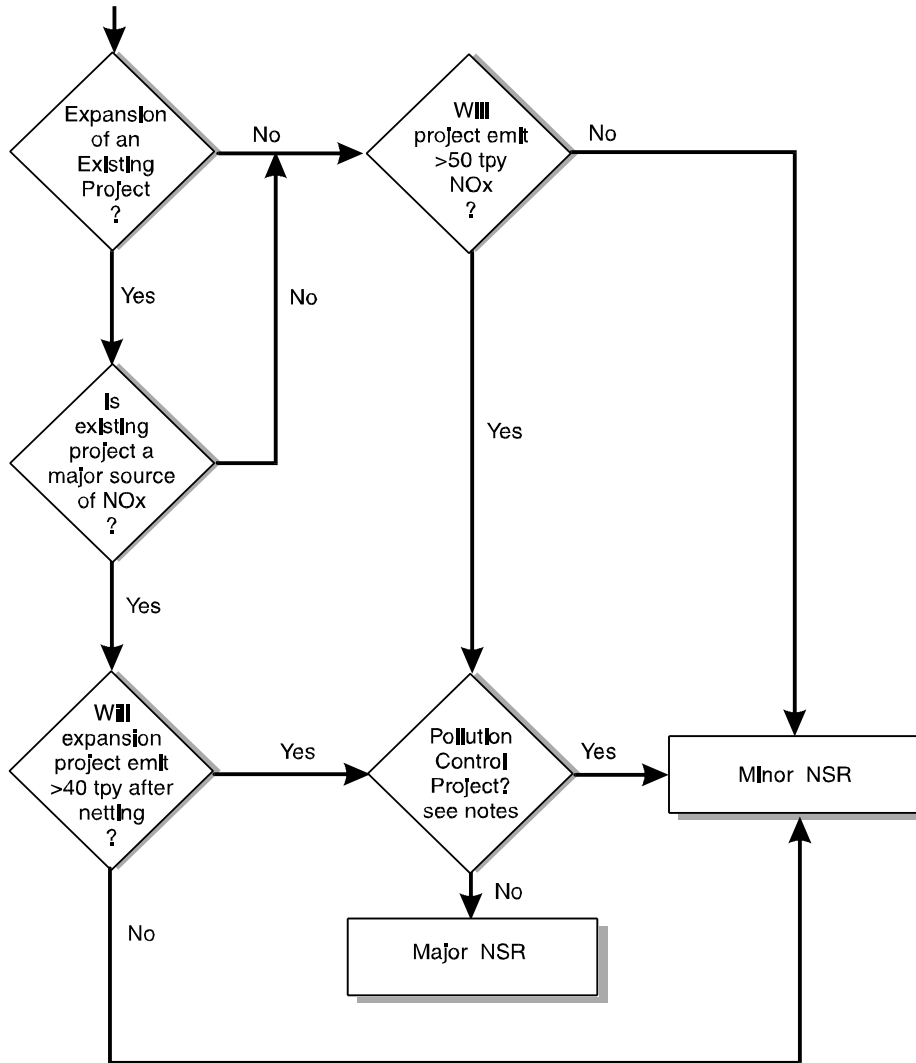
Nonattainment Area Permitting

If a particular area -- usually a county-wide area -- does not meet the NAAQS levels for any of the six criteria pollutants, then it is classified as being in "nonattainment" for that pollutant. A listing of ozone nonattainment areas is provided in Appendix F, since this is the most pervasive nonattainment pollutant and the most likely to affect landfill energy recovery projects. An area may be nonattainment for one or more pollutants. For example, if a county exceeds the NO_x levels set by the NAAQS, but meets the standards for the other pollutants, then the area is classified as nonattainment for ozone only (since ozone attainment is regulated through NO_x and VOCs).

A proposed new emission source or modification to an existing source located in a nonattainment area must

undergo nonattainment major NSR if the source or the modification is classified as major. New sources or modifications are considered major for NO_x or CO if they exceed the limits shown in Table 9.2. Figure 9.3

Figure 9-1 Applicability of New Source Review Requirements in Serious Non-Attainment Areas for Ozone: Emissions of NO_x Used as an Example



Notes:

A Pollution Control Project must be both:

- (a) environmentally beneficial; and
- (b) not cause or contribute to a violation of a NAAQS or PSD increment, or adversely affect an AQRV in a Class I area.

In addition:

- The permitting authority must determine that the project qualifies as a pollution control project.
- The permitting authority must provide an opportunity for public review and comment on the project's application and the proposed NSR exclusion.

shows a simplified flow diagram for determining whether a new source or modification is major in a serious nonattainment area.

Table 9-1 Nonattainment Area Limits For NOx and CO

Pollutant	New Sources are Considered Major if Emissions Exceed (in TPY)	Modifications to an Existing Minor Source are Considered Major if Emissions Exceed (in TPY)	Modifications to an Existing Major Source are Considered Major if Emissions Exceed (in TPY)
NOx			
Marginal	100	100	40
Moderate	100	100	40
Serious	50	50	40
Severe	25	25	25
Extreme	10	10	10
CO			
Moderate	100	100	100
Serious	50	50	50

Two primary requirements must be fulfilled in order to obtain a nonattainment NSR permit for criteria pollutants: (1) The project must use technology that achieves the Lowest Achievable Emissions Rate (LAER) for the nonattainment pollutant, and (2) a source must arrange for an emission reduction at an existing combustion source that more than offsets the emissions from the new project.

Defining the lowest achievable emission rate (LAER) can be a challenge for landfill gas projects. Permitting authorities unfamiliar with the characteristics of landfill gas may expect a landfill gas project to achieve the same LAER as a natural gas project. This can be difficult for a number of reasons, including the inability of the catalysts designed to reduce NO_x emissions to function effectively on landfill gas, the variable flow, composition, and Btu value of landfill gas, and the fact that landfill gas projects are often too small for the use of turbines, which have lower NO_x rates than IC engines, to be economic. Cost, however, is not a consideration in determining the LAER technology.

Obtaining emission offsets to ensure no net change in overall pollutant levels can also be a challenge. Emission offsets are created when emission reductions are achieved at an existing emissions source (typically, an industrial facility) in order to cover the increased emissions of the new source. The most common type of offsets required by the new projects are NO_x offsets because there are many ozone nonattainment areas (i.e. areas whose NO_x and VOC levels do not meet NAAQS), and many combustion sources emit NO_x at high enough levels to become major sources and require offsets. Most of the northeast U.S. is designated as an ozone nonattainment area, for example, known as the Northeast Ozone Transport Region.

The number of offsets required by a project is determined by applying an offsets ratio to its emission level above the threshold. The ratio varies from 1:1.1 to 1:1.5 for ozone, depending upon an area's degree of nonattainment, and is 1:1 for CO and other criteria pollutants. For example, a project proposed for a severe ozone nonattainment area that has the potential to emit 100 tons per year of NO_x would be required to obtain 97.5 tons per year of NO_x offsets.³

NSR Exemption for Pollution Control Projects

On July 1, 1994, EPA's Office of Air Quality and Planning Standards issued guidance to regional and state staff that increases their flexibility in permitting projects that are classified as "pollution control projects". Under the guidance, the permitting authority may exempt the project from major NSR, as long as emissions from the project and minor source requirements are met. In nonattainment

³The number of tons that must be offset is calculated as follows: ["emissions level" (100 tons) **minus** "threshold level for severe nonattainment" (25 tons)] **multiplied by** ["offsets ratio for severe nonattainment" (1.3)].

areas, offsets will still be required, but need not exceed a 1:1 ratio. In order to qualify as a pollution control project, a landfill gas-to-energy project must pass two tests: (1) the environmentally-beneficial test and (2) the air quality impact assessment.

Under the environmentally-beneficial test, the proposed project is evaluated on its overall environmental impact on air quality. If, on balance, there is a beneficial impact on air quality, the project could qualify as a pollution control project. For example, a landfill gas-to-energy recovery project could be considered a pollution control project if it reduces VOCs, even if it generates some NO_x.

Under the air quality impact assessment, the pollution control exclusion will not apply if the emissions from the project would (e.g. NO_x) cause or contribute to a violation of NAAQS or PSD increment, or adversely impact visibility or other Air Quality Related Values (AQRV) in a Class I area [see, e.g., Clean Air Act sections 110(a)(2)(C), 165, 169A(b), 173]. Therefore, where a pollution control project will result in a significant increase in emissions and that increased level has not been previously analyzed for its air quality impact and raises the possibility of a NAAQS, PSD increment, or AQRV violation, the permitting authority is to require the source to provide an air quality analysis sufficient to demonstrate the impact of the project. In the case of non-attainment areas, the State or the source must provide offsetting emissions reductions (at a 1:1 ratio) for any significant increase in a nonattainment pollutant (e.g. NO_x) from the pollution control project. However, rather than having to apply offsets on a case-by-case basis, States may consider adopting specific control measures or strategies for the purpose of generating offsets to mitigate the projected collateral emissions increases from a class or category of pollution control projects.

In addition to passing the two tests, there are two procedural safeguards that a pollution control project must address. First, the project must receive approval from the permitting authority (this is done on a case-by-case basis). Second, the application for exclusion and the permitting agency's proposed decision must be subject to public notice with the opportunity for public and EPA written comment.

This guidance memorandum is included in Appendix E. It is important to recognize that this is a guidance document and not a promulgated rule, which means that permitting authorities may choose to adopt the guidance and exercise greater flexibility, or disregard it.

NOx Emissions from Energy Conversion

Combustion of landfill gas -- in an engine, turbine, or other device -- generates nitrogen oxide (NOx). The amount of NOx generated and emitted depends primarily upon the following two characteristics of the combustion process:

- Air/fuel Ratio: the ratio of air to fuel (i.e., landfill gas) in the combustion chamber is a key factor in determining the quantity of NOx generated from combustion of landfill gas. If air in excess of what is needed to achieve combustion is introduced into the combustion chamber, fewer NOx emissions are generated.
- Residence time: the amount of time that the landfill gas is in the combustion chamber has a significant effect on NOx formation. Longer residence times allow greater quantities of NOx to be formed and ultimately emitted.

The air/fuel ratio and residence time vary between the major technologies used in landfill gas-to-energy applications (i.e., internal combustion engines and combustion turbines) as well as among different types of engines; therefore, NOx emissions per cubic foot of landfill gas burned as fuel in a combustion device also varies. When internal combustion engines and turbines are used in conventional natural gas applications, catalysts are often used to reduce NOx emissions. To date, catalysts have not proven effective in landfill gas applications because the impurities found in landfill gas quickly limit the catalysts' ability to control NOx emissions.

Table 9.3 provides emissions factors that can be used to estimate the range of NOx emissions that could be expected from a landfill gas project employing internal combustion engines (IC) or combustion turbines (CT). As the table indicates, the potential emission factors for IC engines span a relatively large range; the lower end of the range is represented by lean-burn engines, which use excess air in the combustion process, while the high end is represented by naturally aspirated IC engines. Depending on the specific type of engine being used, it should be possible to select an appropriate emission factor from within this range. In contrast, only one emission factor is provided for combustion turbines. This factor is appropriate for the most common type of turbine used for landfill gas applications (the Solar Centaur gas turbine).

Table 9-1 Emission Factors By Technology Type

	IC Engine	CT
Emission factor (lb NO _x /MMBtu)	0.22 - 0.54	0.12

Annual NO_x emissions can be calculated by multiplying the appropriate emission factor from Table 9.3 by the energy content (in MMBtu/year) of the landfill gas fuel. The energy content can be calculated easily from the landfill gas flow, as follows:

$$\text{Energy Content (Btu/Yr)} = \text{LFG (cfd)} * \frac{\text{Btu}}{\text{cf}} * \underline{365 \text{ days}}_{\text{yr}}$$

Landfill gas typically contains about 500 Btu per cubic foot. This can be used as a default if the Btu value of landfill gas at a specific site is not known. For a 5 million ton landfill with a gas flow of about 3 million cubic feet per day, the energy content would therefore be calculated as follows:

$$3 \text{ mmcf} * \frac{500 \text{ Btu}}{\text{cf}} * 365 = 548 * 10^3 \text{ MMBtu/yr}$$

Table 9.4 illustrates a potential range of emissions in tons of NO_x per year for typical 1, 5, and 10 million ton landfills. As Table 9.4 illustrates, NO_x emissions from IC engines are substantially higher than emissions from CTs. Landfills located in ozone non-attainment areas may therefore find that CTs are the most appropriate technology for medium or larger sized landfill gas projects. The following sections describe the differences among IC engines and between IC engines and CTs that result in the large range of emissions.

Table 9-1 NO_x Emissions Table

Landfill Characteristics		Estimated NO _x Emissions (TPY)	
Waste in Place (million ton)	Landfill Gas Flow (1000 cfd)	IC Engine	CT
1	642	13 - 32	n/a
5	2988	60 - 147	35
10	5264	106 - 260	60

Internal Combustion Engines - There are two basic types of IC engines: naturally aspirated and lean-burn. Naturally aspirated IC engines draw combustion air and landfill gas through a carburetor in stoichiometric proportions, much the same way that an automobile equipped with a carburetor would draw its air/fuel mixture. Just enough air is drawn into the combustion chamber to ignite the air/landfill gas mix. In addition, residence time in the combustion chamber is relatively long. Therefore, this type of engine emits relatively high levels of NO_x, and is represented by the high end of the range shown in Table 9.4. For landfill gas-to-energy recovery projects, this type of engine is best suited for smaller projects in ozone attainment areas.

Lean-burn IC engines combust landfill gas with air in **excess** of the stoichiometric mix. Since this type of engine uses a mixture with excess air, it provides both greater engine power output and fewer NO_x emissions than a comparable naturally aspirated engine. This type of engine can be expected to emit NO_x emissions on the low end of the range shown in Table 9.4. It should be noted that manufacturers of these engines are continually refining them and that newer, even lower NO_x emitting engines are expected to be commercially available soon. In addition, newer, more effective add-on control systems are in development.

Combustion Turbines - CTs utilize large amounts of excess air and have relatively short residence time. These factors combine to greatly reduce the amount of NO_x emitted relative to internal combustion engines.

These lower emissions may be a significant benefit of using a CT, particularly for medium to large landfill gas energy recovery projects located in ozone non-attainment areas. However, because CTs are not cost-effective at smaller projects (i.e., less than 3 MW), these projects typically do not have the option of using CTs.

9.4 LOCAL ISSUES

Local approval of a project is crucial to its success. This approval refers not only to the granting of permits by local agencies, but also to community acceptance of the project. Strong local sentiment against a project can make permitting difficult, if not impossible.

9.4.1 Zoning and Permitting

Project siting and operation are governed by local jurisdictions (in addition to federal regulations); therefore, it is imperative to work with regulatory bodies throughout all stages of project development in order to minimize permitting delays which cost both time and money. This is especially important since the pollution prevention benefits of landfill gas projects may not initially be considered and because different agencies' rules can often be conflicting [Pacey, Doorn, Thorneloe, 1994].

Zoning/Land Use

The first local issue to be addressed is the compatibility of the project site with community land use specifications. Most communities have a zoning and land use plan that identifies where different types of development are allowed (e.g., residential, commercial, industrial). The local zoning board determines whether or not land use criteria are met by a particular project, and can usually grant variances if conditions warrant.

A landfill gas project site will likely require an industrial zoning classification. One advantage of landfill gas projects is that they are usually located at the landfill site, thus zoning reclassification may not be necessary, especially if the landfill is still active.

Permitting Issues

In addition to land use specifications, local agencies have jurisdiction over a number of other project parameters, such as the following:

Noise - Most local zoning ordinances stipulate the allowable decibel levels for noise sources, and these levels vary, depending on the zoning classification at the source site (e.g., a site located near residential areas will have a lower decibel requirement than one located in an isolated area). Even enclosed facilities are usually required to meet these requirements; therefore, it is important to keep them in mind when designing project facilities.

Condensate - There may be unique permitting or treatment requirements for landfill gas condensate. While some landfill gas projects can return the condensate to the landfill, many dispose of condensate through the public sewage system after some form of on-site treatment [Berenyi and Gould, 1994]. It is possible that the condensate may contain high enough quantities of heavy metals and organic chemicals for it to be classified as a hazardous waste, thus triggering additional, federal regulation.

Wastewater - The primary types of wastewater likely to be generated by a landfill gas power project include maintenance/cleaning wastewater, domestic wastewater, and cooling tower blowdown. The municipal engineer's office should be contacted to provide information about available wastewater handling capacity, and any unique condensate treatment requirements or permits for landfills. The wastewater treatment facility operator is likely to have standards governing the pollutant concentrations in incoming wastewater streams. For projects that intend to discharge wastewater into rivers, lakes, or other surface water (typically only the large power projects that use a steam cycle), a National Pollution Discharge Elimination System (NPDES) permit will be required. The authority to issue these permits is delegated to state governments by the U.S. EPA.

Water - Water requirements will depend on the type and size of the project and the environmental control technologies used. The city engineer's office should also be able to provide data about available water supply capacity. If current

facilities cannot meet the needs of the project, then new facilities (e.g., pipeline, pumping capacity, wells) may need to be constructed. Groundwater permits could be required if new wells are needed to supply the project's water needs. (Note that the landfill itself, if active, will already be required by RCRA Subtitle D to monitor groundwater.)

Solid waste disposal - The only solid wastes generated by a landfill gas power project will likely be packaging materials, cleaning solvents, and equipment fluids. While there may only be a small amount of solid waste generated, it must be properly disposed of; which may be an important consideration if the project landfill is closed.

Stormwater management - Public works departments regulate stormwater management, and will require a permit for discharges during construction and operation. Good facility design that maintains the predevelopment runoff characteristics of the site will allow the project to easily meet permitting requirements.

Stack height - Local codes may limit stack heights, especially near airports or landing fields. Project design (e.g., plant layout, flare design) must take these limits into account.

Other - There may be other issues that local agencies oversee. It is important to find out what these issues are by contacting local authorities, especially since they vary among project sites. As an example of such other issues, Box 9.1 partially lists the local permits that were required for the Fresh Kills Landfill Methane Recovery Project, located in New York.

9.4.2 Community Acceptance

As any project developer will attest, community support is extremely important to the success of a project, especially since some communities require public participation in project zoning/siting cases. Like landfills, many power projects in the past have encountered local opposition such as the "not in my backyard (NIMBY)" syndrome, or false perceptions of project dangers (e.g., explosion risks, adverse health effects from electromagnetic fields). Therefore, it is important to educate the public and to develop a working relationship with the host community in order to dispel any fears or

doubts about the expected impact of the project. Project details should always be presented in a very forthcoming and factual manner.

Landfill gas-to-energy projects bring many benefits to the host community (e.g., improved air quality, reduction of landfill gas odor and explosive potential). These benefits should be emphasized during the permitting process.

Box 9-1 Some of the Local Permits Required for the Fresh Kills Landfill Methane Recovery Project

<u>Agency</u>	<u>Permits</u>
Bureau of Gas and Electricity	Certification that all equipment is explosion proof
Division of Fire Protection	One hundred percent x-ray of all pipe joints
Department of Sanitation	Site approval
Board of Standards and Appeals	Approval of equipment on site
Community Planning Board of Staten Island	Compliance with height restrictions
Department of Environmental Protection	Air Quality approval
Department of Ports and Terminal	Well permits
Department of Buildings	Construction approvals

Source: "Regulatory Barriers to Landfill Gas Recovery Projects"

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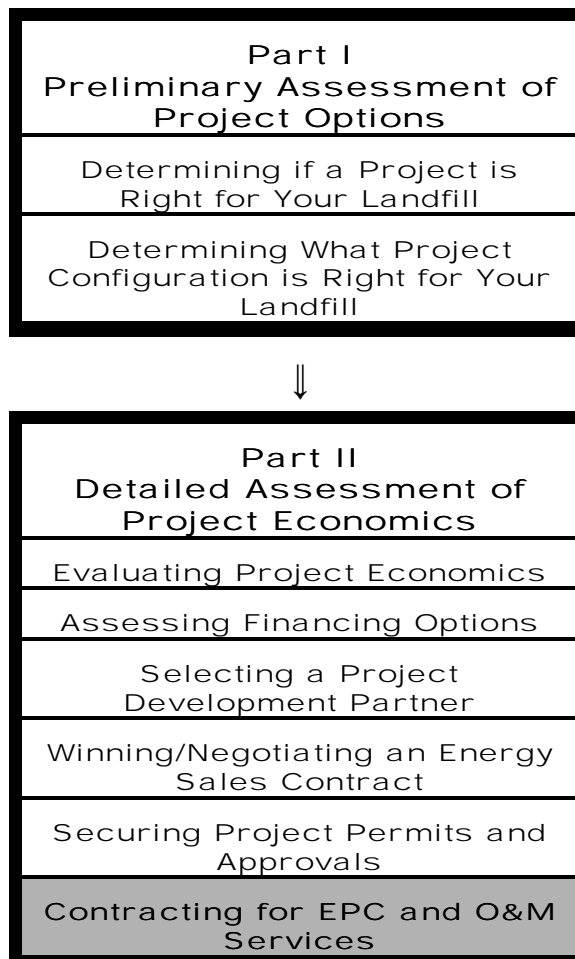
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10. Contracting For EPC And O&M Services

As discussed in Chapter 7, many landfill owners may decide to work with firms with extensive experience during project development. Likewise, because the construction and operation of landfill gas energy recovery projects are complex processes, they may be best managed by a firm with proven experience, gained over the course of implementing similar landfill gas projects. Landfill owners that choose to contract with an engineering, procurement, and construction (EPC) firm and/or an operating firm should be aware of some of the basic elements of effective contracting. This chapter provides some contracting considerations for landfill owners, and lists operating insights gained from a survey of technical literature and interviews with landfill energy project owners, developers, and operators.

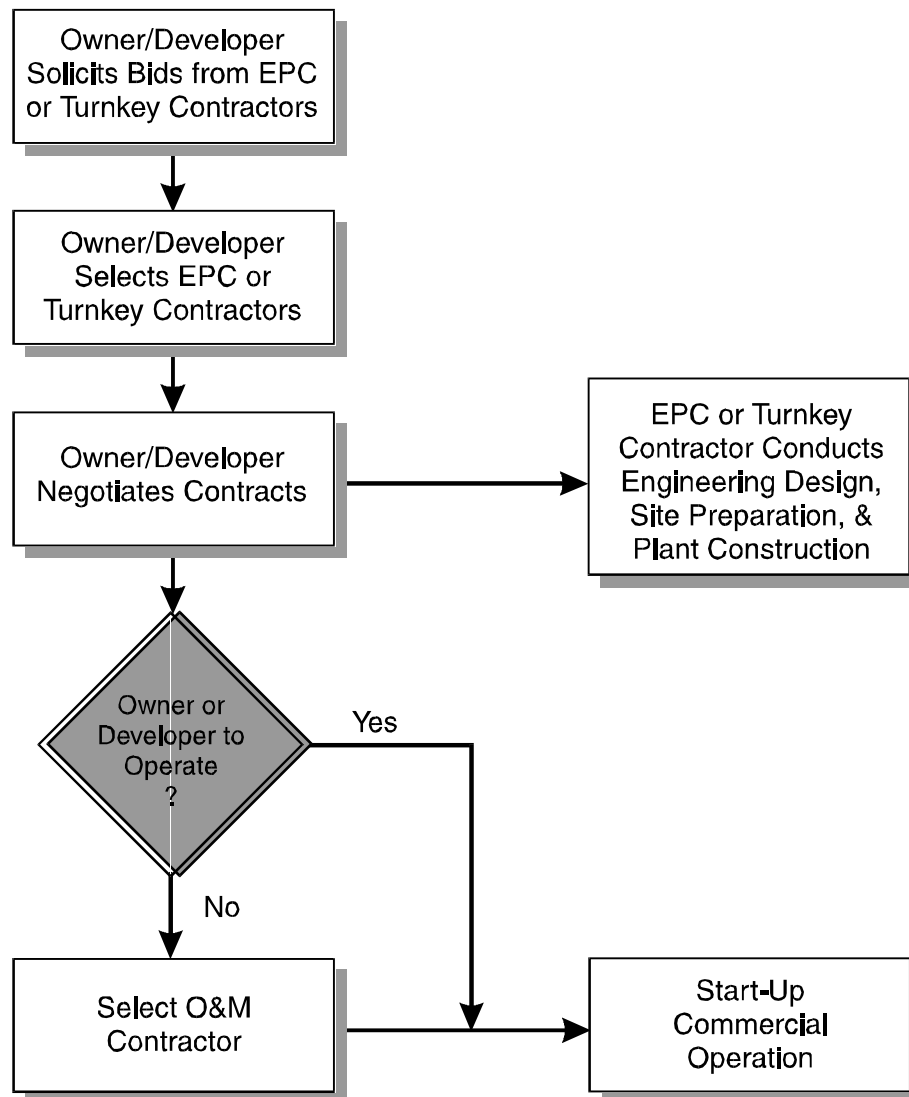
The Project Development Process



10.1 EPC/TURNKEY CONTRACTING

After a project proponent has secured an energy sales contract and the required permits and approvals, he or she may contract with an EPC or turnkey firm who will take responsibility for construction of the project. The tasks performed by an EPC contractor include: conducting engineering design, procuring the equipment, preparing the project site for construction, and pre-operation start-up testing. A turnkey contractor extends its services beyond those of an EPC contractor by taking on many of the owner's and developer's duties as well, which include environmental permitting, regulatory licensing, interconnections, and project management.

Figure 10-1 The EPC/Turnkey Contracting Process



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The process of contracting with an EPC or turnkey firm is charted in Figure 10.1. As this figure shows, the process has several key steps, beginning with the landfill owner and/or project developer soliciting bids from contractors and ending with the selection of a contractor who will take the project to commercial operation. Along the way, the owner/developer and its chosen contractor must conduct engineering design, site preparation, and plant construction.

An effective EPC or turnkey contract clearly establishes the responsibilities of each contracting entity, and it also should mesh with other existing project documents. The contractor is generally responsible for engineering and building the plant to predetermined specifications, making sure that project construction milestones are met, and ensuring that acceptable performance is achieved at the commercial operation date. The landfill owner and/or project developer is generally responsible for making sure funds are available as needed, that the site is available and ready, and that provisions are made for any necessary interconnections related to gas utilization. The elements of an effective contract are described in Table 10.1.

Table 10-1 Elements of an Effective EPC or Turnkey Contract

Element	Items to be Specified
Commercial operation date	Date on which facility should achieve commercial operation (should precede date in Power Sales Agreement (PSA))
Milestones	Engineering completion, construction commencement, engine delivery, start-up
Cost, rates, and fees	Structures include: fixed EPC or turnkey price, hourly labor rates, cost caps, fee amount or percentage
Performance guarantees	Specified output (kW, mcf), heat rate, availability, power quality, gas quality (should match PSA)
Warranties	Output, performance degradation, heat rate, outage rates, component replacement costs
Owner's acceptance criteria and procedure	Testing methods and conditions, calculation formulae
Bonus amounts and conditions	Bonus for early completion, exceeding specifications
Liquidated damages and conditions	Damages for late completion, failure to meet specifications
Assignment	Ability to assign agreement to subsidiary, partnership, bank

Because of the importance of securing and fulfilling the power sales agreement, the EPC contract should specifically recognize each entity's role in meeting its key elements. These elements include:

- Commercial operation date;
- Project output (e.g., kW electricity, mcf gas) and heat rate;
- Plant availability; and
- Interconnection requirements; and
- Maintenance provisions.

Power project developers usually prefer to sign fixed-price EPC or turnkey agreements, which enable the plant's installed cost to be known up front. If a fixed-price contract is selected, then the price, scope of services, and other terms must be clearly specified in the contract. The contract price should have an underlying budget that includes plant components as well as the services mentioned above. The most important budget items are listed in Box 10.1.

Box 10.1 EPC and Turnkey Budget Items

The EPC budget for a landfill gas energy recovery project should include at least the following items:

- Engine skid (e.g., IC engine, CT, turbine/generator)
- Engine auxiliaries (e.g., lubricating oil system, cooling system, air intake manifold and filters, intake and exhaust silencers, fuel injection system, hydraulic system, piping, and ductwork)
- Foundations and sitework
- Gas processing system (e.g., filters, refrigeration)
- Gas compressor(s)
- Emissions controls
- Plant electrical equipment and switchgear
- Step up transformer(s)
- Interconnections (electric, water, landfill gas)
- Back-up fuel capability/storage
- Automatic control system
- Gas and electric metering
- Water treatment and cooling
- Building/enclosure
- Fire protection system
- Engineering costs and associated expenses
- EPC contingency

A turnkey facility provider should include the following additional items:

- Gas collection system (if applicable)
- Additional interconnection costs (e.g., rights-of-way, piping, transmission lines)
- Permitting costs, legal, administration expenses, insurance
- Financing costs (if applicable)
- Escalation during construction
- Interest during construction
- Contingency
- Fee

Contracting with a turnkey plant provider is an extension of contracting for EPC services, because the turnkey provider usually agrees to include within its scope of services the owner's and developer's duties as well as EPC contracting. A turnkey plant provider is usually an EPC

firm or developer who agrees to develop and build a facility for a fixed price. As shown in Table 1O.1, a turnkey contract must include the following items that are in addition to the typical EPC contract items: turnkey price, development milestones, and contractor's responsibilities.

1O.2 O&M SERVICES CONTRACTING

Many landfill owners and/or project developers do not wish to take on the day-to-day responsibility of operating their landfill gas energy recovery project due to lack of manpower, experience, or desire. When this is the case, hiring an O&M contractor may be an attractive alternative. A survey of existing and planned landfill gas energy recovery projects shows that about 80% of gas collection systems and 89% of gas processing/energy recovery systems are operated by private O&M firms or in partnership with a private O&M firm [Berenyi and Gould, 1994].

When contracting with the provider of O&M services, the landfill owner should talk to several competing companies and select a winner based on experience, price, and terms. The O&M company should have experience operating and maintaining similar facilities, and should demonstrate that its accumulated experience will be applied in the form of qualified personnel and ongoing training activities. Competing O&M companies should be asked to submit hourly rates, expected annual budgets for O&M services, and fees.

It is important that the scope of O&M services be well defined so all bids can be compared on a consistent basis. For example, it should be clearly specified whether O&M services are to be provided for the gas collection system and the energy recovery system both or only for one. The EPC contractor or equipment vendor can usually supply estimates for the costs and duration of periodic maintenance procedures and major overhauls.

The facility owner may choose to provide incentives to the O&M company in the form of contractual bonus/damages clauses to improve performance. For example, if maximizing annual operating hours is important to project economics, then the facility owner might propose a cash bonus for plant availability or kWh generation which exceeds a predetermined amount.

1O.3 GOOD O&M PRACTICES

The power production and direct use technologies for landfill gas have been improved since their first use about 15 years ago. Over this time, many of the operational problems encountered have been addressed with technology or procedural improvements. Therefore, many of the technical problems found in the landfill gas literature are no longer major obstacles to successful landfill gas energy recovery (in fact, some of the problems are no longer obstacles at all).

In a recent survey, however, at least 22% of operating landfill gas energy recovery projects reported experiencing operating interruptions for reasons other than planned maintenance [Berenyi and Gould, 1994]. Of the 29 plants that reported unplanned interruptions, only two experienced problems resulting in plant failure. The main reason cited for interruptions was gas collection or processing equipment problems. Other specific operational problems related to the gas collection system causing plant interruptions include pipe blockage or breakage and lack of landfill gas. In many cases, such problems can be avoided with careful equipment selection and operation and maintenance. Good O&M procedures are always important to the success of energy projects. They are even more important with landfill gas projects due to the impurities and variability found in landfill gas. This section presents insights on how to prevent or minimize operating problems.

10.3.1 Collection Systems

Before sizing an energy recovery project, a project developer should estimate landfill gas quantity as accurately as possible to prevent oversizing the equipment and inefficiencies due to gas shortfall during operation. After project start up, proper operation and maintenance of the gas collection system is necessary to balance offsite gas migration control with optimal equipment performance.

Collection system problems may occur when wellfields are located in active landfill areas; therefore, it is important to account for future landfill operations when designing the collection system. By planning ahead, plant shutdowns or reduced output levels due to collection system repairs may be avoided. Two examples of potential problems that may be prevented by good planning are:

- Decreased gas recovery rates due to limited well accessibility caused by depositing additional refuse vertically on top of existing wells [WMNA, 1992];

- Reduced landfill gas generation and quality caused by reopening a section of inactive landfill where an existing well is located.

Good operating procedures, in addition to good system design, will also help to prevent problems. For example, routine monitoring and tuning of wells will ensure that gas quality is suitable for the efficient operation of the recovery equipment.

10.3.2 Energy Recovery Systems

While energy recovery technologies have been adapted to landfill gas applications, several important operating considerations must be kept in mind to minimize or avoid problems that arise due to landfill gas's corrosive nature and low Btu content.

IC Engines

IC engines are the most susceptible of the three common electric generation technologies to the effects of corrosion [Anderson], which attacks engine parts and causes deposit buildup. Experience has shown the following steps to be useful in combatting corrosion in IC engines used at landfills:

- Perform frequent oil checks and changes.
- Use an oil with a high alkalinity reserve (i.e., oil with a high total base number) [Schleifer, 1988]. Oils with a total base number (TBN) of 10 are commonly used [WMNA, 1992].
- Use oil filters that have been treated with chemicals to neutralize acids from the combustion of landfill gas [Anderson].
- Chrome-plate components that are subject to attack [Pacey, Doorn, and Thorneloe, 1994].

CTs and Boiler/Steam Turbines

Although CTs and boiler/steam turbines are more resistant to corrosion than engines, they each have their own set of operational considerations:

- An extra filtration step may be necessary if the compressors used to reach the required pressure for CT operation cause oil entrainment and heating of the landfill gas [WMNA, 1992].

- Due to the Btu variability in landfill gas, CT fuel/air controls must react very quickly. If they do not, the temperature will overshoot and automatically shut down the CT. To avoid temperature overshoot, landfill gas fueled-CTs should be operated at a lower temperature setpoint than CTs using conventional fuels [Pacey, Doorn, and Thorneioe, 1994].
- Silica deposits, which can lead to turbine failure, can be prevented with gas refrigeration to condense dimethyl siloxane before combustion; however, this step may not be economically justified [Anderson, WMNA, 1992].
- Boiler tubes should be designed to withstand the corrosiveness of landfill gas.

The over 200 existing and planned landfill gas energy recovery projects illustrate that the technology is well-demonstrated and generally reliable. As long as projects are well planned, executed, and maintained, they can perform up to or beyond expectations for many years.

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Listing of Municipal Solid Waste Landfill Organizations and Related Service Providers

Solid Waste Association of North
America (SWANA)
P.O. Box 7219
Silver Spring, MD 20910-7219
Contact: Michael Ohlsen
Phone: (301) 585-2989
Fax: (301) 585-7068

Environmental Industry Associations
(EIA)/ National Solid Wastes
Management Association (NSWMA)
4301 Connecticut Avenue, NW
Suite 300
Washington, DC 20008
Contact: Ed Repa
Phone: (202) 244-4700
Fax: (202) 966-4818

Association of State and Territorial
Solid Waste Management Officials
(ASTSWMO)
Hall of States
Suite 343
444 North Capitol Street, NW
Washington, DC 20001
Phone: (202) 624-5828
Fax: (202) 624-7875

National Business Industries
Association
122 C Street, NW
Fourth Floor
Washington, DC 20001
Phone: (202) 383-2540
Fax: (202) 383-2670

Department of Energy Regional
Biomass Energy Program
Office of National Programs
U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585
Contact: N. Michael Voorhies,
National Coordinator
Phone: (202) 586-9104

American Public Works Association
1301 Pennsylvania Avenue, NW
Suite 501
Washington, DC 20004
Contact: Sarah Layton
Phone: (202) 347-0612
Fax: (202) 737-9153

Regional Biomass Energy Programs:

Northeast Region
Richard Handley, Program Manager
CONEG Policy Research Center, Inc.
400 North Capitol Street, NW
Suite 382
Washington, DC 20001
Phone: (202) 624-8454
Fax: (202) 624-8463

Northwest Region
Jeff James, Program Manager
U.S. Department of Energy
Seattle Regional Support Office
905 NE 11th Avenue
Portland, OR 97232
Phone: (503) 230-3449
Fax: (503) 230-4973

Regional Biomass Energy Programs (continued):

Great Lakes Region
Frederick J. Kuzel
Council of Great Lakes Governors
35 East Wacker Drive #1850
Chicago, IL 60601
Phone: (312) 407-0177
Fax: (312) 407-0038

Southeast Region
Philip Badger, Program Manager
Tennessee Valley Authority
435 Chemical Engineering Building
Muscle Shoals, AL 35660
Phone: (205) 386-3086
Fax: (205) 386-2963

Western Region
Dave Swanson
Western Area Power Authority
1627 Cole Boulevard
P.O. Box 3402
Golden, CO 80401
Phone: (303) 231-1615
Fax: (303) 231-1632

U.S. Environmental Protection Agency Offices

EPA Region	EPA Address	States Included in Region	Regional Contact	Phone	Fax
	Landfill Methane Program 401 M St., SW, 6202J Washington, DC 20460	All		202-233-9042	
1	John F. Kennedy Federal Bldg. One Congress Street Boston, MA 02203	CT, ME, MA, NH, RI, VT	Jeann e Cosgr ove	617-565-9451	617-565-4940
2	Federal Office Bldg. 26 Federal Plaza New York, NY 10278	NJ, NY, Puerto Rico, Virgin Islands	Christi ne DeRos a	212-637-4022	212-637-3998
3	Curtis Building Sixth and Walnut Streets Philadelphia, PA 19106	DE, DC, MD, PA, VA, WV	Jim Topsal e	215-566-2190	215-566-2124
4	345 Courtland, NE Atlanta, GA 30308	AL, FL, GA, MS, KY, NC, SC, TN	Scott Davis	404-347-5014 Ext. 4144	404-347-3059

EPA Region	EPA Address	States Included in Region	Regional Contact	Phone	Fax
5	230 South Dearborn St. Chicago, IL 60604	IL, MN, MI, OH, IN, WI	Charles Hatten	312-886-6031	312-886-5824
6	First International Bldg. 1202 Elm Street Dallas, TX 75270	AR, LA, NM, OK, TX	Mick Cote	214-665-7219	214-665-2164
7	324 E. Eleventh Street Kansas City, MO 64106	IA, KS, MI, NE	Ward Burns	913-551-7960	913-551-7065
8	1860 Lincoln Street Denver, CO 80295	CO, MN, ND, SD, UT, WY	John Dale	303-312-6934	303-312-6064
9	215 Freemont Street San Francisco, CA 94105	AZ, CA, HI, NV, Guam, American Samoa	Patricia Bowlin	415-744-1188	415-744-1076
10	1200 Sixth Avenue Seattle, WA 98101	WA, OR, ID, AK	John Keenan	206-553-1817	206-553-0110

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APPENDIX J
GLOSSARY OF TERMS

Glossary of Terms

AFFECTED LANDFILL: Landfills that meet criteria set by the EPA under authority of Title I of the Clean Air Act for capacity, age, and emission rates; affected landfills are required to collect and combust their landfill gas

ATTAINMENT AREA: A geographic region that meets National Ambient Air Quality Standards (NAAQS) for specific air pollutants

AVOIDED COST: The cost a utility would incur to generate the next increment of electric capacity using its own resources; many landfill gas projects' buyback rates are based on avoided costs

BASELOAD: A term referring to the energy use of a facility that has a consistent, year-round need for energy; baseload can also refer to the minimum amount of electricity supplied to a facility on a continuous basis

BEST AVAILABLE CONTROL TECHNOLOGY (BACT): The most stringent technology available for controlling emissions; major sources are required to use BACT, unless it can be demonstrated that it is not feasible due to energy, environmental, or economic reasons

BUYBACK RATE: The price a utility will pay a third party supplier for electricity or gas

CAPACITY FACTOR: The ratio of the energy produced by a piece of equipment during a given time period to the energy the unit could have produced if it had been operating at its full rated capacity

CAPACITY PRICE: The fixed price in \$/kW a utility pays a third party supplier for a guaranteed availability of generating capacity; capacity price is based on the capital costs of a generating unit

CAPITAL CHARGE RATE: A number used to convert

the installed cost of a power project into a levelized capital cost that can be charged to the project in each year of the project life

CAPITAL COST: The total installed cost of equipment, emissions control, interconnections, gas compression, engineering, soft costs, etc. for landfill gas projects

COGENERATION: The consecutive generation of useful thermal energy and electric energy from the same fuel source

COMBINED-CYCLE: Technology in which waste heat from a gas turbine is used to produce steam in a waste-heat boiler; the steam is then used to generate electricity in a steam turbine/generator

CONDENSATE: Liquid formed when warm landfill gas cools as it travels through the collection system

COST OF CAPITAL: The cost to a company of acquiring funds to finance the company's capital investments and operations

DEBT COVERAGE RATIO: Ratio of operating income to debt service requirement, usually calculated on an annual basis

DEBT SERVICE REQUIREMENT: Monthly requirement to meet the principal and interest amounts of a loan

DISPLACEMENT SAVINGS: Savings realized by displacing purchases of natural gas or electricity from a local utility by using landfill gas

EPC FIRM: A company that provides engineering, procurement, and construction services

FLARE: A device used to combust excess landfill gas that is not used in energy recovery; flares may be open or enclosed

GREENHOUSE GAS: A gas, such as carbon dioxide or methane, which contributes to global warming

GROSS POWER GENERATION POTENTIAL: The installed power generation capacity that landfill gas flows can support

HEAT RATE: A measure of generating unit thermal efficiency, expressed in units of Btu/kWh

LOWEST ACHIEVABLE EMISSIONS RATE (LAER): The most stringent technology available for controlling emissions; major sources are required to use LAER (cost is not a consideration in determining the LAER technology)

MAJOR SOURCE: New emissions sources or modifications to existing emissions sources that exceed NAAQS emission levels

METHANE (CH₄): The major component of natural gas and landfill gas; produced in landfills when organic matter in waste decomposes

METRIC TON: Measurement of mass; one metric ton equals one megagram (Mg)

MINOR SOURCE: New emissions sources or modifications to existing emission sources that do not exceed NAAQS emission levels

NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS): Air quality standards, established by the Clean Air Act, for six criteria pollutants

NET PRESENT VALUE (NPV): The amount of money, that if invested today at a given rate of return, would be equivalent to a fixed amount to be received at a specified future time

NEW SOURCE REVIEW (NSR): Process by which an air quality regulatory agency evaluates an application for a permit to construct a new generating facility

NONATTAINMENT AREA: A geographic region designated by the EPA that exceeds NAAQS for one or more criteria pollutants

NON-METHANE ORGANIC COMPOUNDS (NMOCs): Compounds found in landfill gas which affect human health and vegetation; NMOCs include several compounds that are known carcinogens to humans

PARASITIC LOAD: The electric load required to run generation equipment; contributes to the difference between gross and net output

PREVENTION OF SIGNIFICANT DETERIORATION (PSD): Regulations designed to limit the increase of criteria air pollutants in attainment areas

PRO FORMA: A computer model of project cash flows over the life of the project, usually containing several standard items

PROJECT FINANCE: A method for obtaining commercial debt financing for the construction of a facility where lenders look to the creditworthiness of the facility to ensure debt repayment, rather than to the assets of the project developer

PUMP TEST: A procedure used to determine the gas generation rate of a landfill; it involves drilling test wells and installing pressure probes

PUBLIC UTILITIES REGULATORY POLICIES ACT (PURPA): Act that requires utilities to purchase the electric output from QFs at the utility's avoided cost

QUALIFYING FACILITY (QF): A cogenerator or small power producer, as defined by PURPA, that is entitled to special regulatory treatment; utilities are required to purchase the electrical output from QFs at the utility's avoided cost

RATE OF RETURN (ROR) ON EQUITY: Financial measurement used to judge the percent of return

on equity capital used in business

RENEWABLE ENERGY PRODUCTION INCENTIVE (REPI): Incentive established by the Energy Policy Act, that is available to renewable energy power projects owned by a state or local government or nonprofit electric cooperative

REQUEST FOR PROPOSALS (RFP): A solicitation by a utility for project proposals

ROYALTIES: Compensation given to a landfill owner for gas rights

SENIOR DEBT LENDER: Institution or person who lends money with the intention that the debt will be repaid before project earnings get distributed to equity investors

SOFT COSTS: Transaction and legal costs, escalation during construction, interest during construction, and contingency costs associated with a project

STANDARD OFFER: A power purchase agreement, sanctioned by the state utility commission, that is typically based on avoided costs

SUBORDINATED DEBT: Money that is repaid after any senior debt lenders are paid and before equity investors are paid

VOLATILE ORGANIC CHEMICALS (VOCs): Chemicals found in landfill gas that are contributors to smog

WHEELING: The transmission of electricity owned by one entity using the facilities owned by another entity (usually a utility)